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A SIMULATION MODEL TO
EVALUATE CLOSE AIR SUPPORT
KILL-TO-LOSS RATIOS

THESIS

AFIT/GST/OS/83M-5

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AIR SUPPORT KILL-TO-LOSS RATIOS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

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Preface

The purpose of this research effort was to create a SLAM simulation model with which to study the close air support mission in Central Europe. Our experience flying this mission and our knowledge of the difficulties associated with the European tactical environment led to our interest in this subject area.

We limited the scope of the model to an analysis of two aircraft operating along a small segment of the FEBA. The air defense systems pitted against the aircraft were limited to the radar controlled systems of a Soviet division. Kill-to-loss ratios were analyzed as a function of air defense threat level, availability of enemy early warning radar, and aircraft airspeed, penetration distance, and weapons load. Though limited in scope we feel this analysis provides valuable insights into the complexity of the close air support mission.

We would like to thank our advisor, Maj. Joseph W. Coleman of the Air Force Institute of Technology, for his guidance during the completion of this study. In addition, we are grateful to Lt. Col. Peter B. Bobko of the Air Force Institute of Technology, who provided valuable technical advice during the writing of this report. Finally, we wish to acknowledge our gratitude to [REDACTED], for her substantial contribution in typing this thesis.

Gary G. Kizer

Donald W. Neal

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List of Abbreviations

AAAAnti-Aircraft Artillery
ABCCCAirborne Command and Control Center
AFACAirborne Forward Air Controller
AGLAbove Ground Level
ALOAir Liaison Officer
ANOVAAnalysis of Variance
AvArea of Vulnerability
AWACSAirborne Warning and Control System
CASClose Air Support
CBUCluster Bomb Unit
C³Communications, Command, and Control
CEPCircular Error Probable
CPContact Point
CRCControl and Reporting Center
DASCDirect Air Support Center
dbdecibels
ECCMElectronic Counter-Counter Measures
ECMElectronic Counter Measures
ERPEffective Radiated Power
EWEarly Warning
FACForward Air Controller
FEBAForward Edge of Battle Area
FLIRForward Looking Infrared
FOForward Observer
GAcceleration Force of Gravity

GFACGround Forward Air Controller
 GrGain of Radar Antenna
 IPInitial Point
 IRInfrared
 J/SJamming to Signal Ratio
 LANTIRNLow Altitude Navigation and Targeting
 Infrared System For Night
 LCLine of Contact (FEBA)
 LRLethal Radius
 NATONorth Atlantic Treaty Organization
 NMNautical Mile
 PKProbability of Kill
 PKSSSingle Shot Probability of Kill
 PrTransmitted Power of Radar
 PRFPulse Repetition Frequency
 PUPPull Up Point
 RCSRadar Cross Section
 RHAWRadar Homing and Warning
 RTBReturn to Base
 SAMSurface to Air Missile
 SPSSStatistical Package For the Social Sciences
 TACTactical Air Command
 TACPTactical Air Control Party
 TACSTactical Air Control System
 TAGSEMTactical Air to Ground Simulation
 TASVALTactical Aircraft Effectiveness and Survivability
 in Close Air Support Anti-Armor Operations

TOFTime of Flight

USAFUnited States Air Force

V/STOLVertical/Short Take-off and Landing

Abstract

Effective employment of close air support resources is essential if the rapid forward advance of a numerically superior enemy ground army is to be successfully stopped. The objective of this thesis was to develop a methodology that could examine and evaluate the various factors and interactions that influence the effectiveness of the close air support mission. The problem was studied in the context of the terrain of Central Europe and the anticipated threats for that region.

A model of the close air support environment was built using the SLAM computer simulation language. Five factors and their interactions were analyzed in the model. Those factors were aircraft airspeed, aircraft weapons load, penetration distance behind the FEBA, the availability of enemy early warning radars, and the total number of threats in the area. The level of each factor was varied to determine its effect and interaction with the other factors. As the aircraft flies through its profile, defensive systems that are within range will shoot at it provided they are not engaged with another aircraft, blocked by terrain, or prevented from shooting because of a low probability of kill. The threats can be moved around in the model as desired. Self protective jamming is employed by the aircraft.

Airspeed by itself does not significantly affect the

aircraft kill-to-loss ratio. It does, however, contribute significantly through interaction with the other factors. Each of the other factors significantly affects the kill-to-loss ratio. Penetration distance behind the FEBA has the greatest affect upon kill-to-loss ratio.

A SIMULATION MODEL TO EVALUATE
CLOSE AIR SUPPORT KILL-TO-LOSS RATIOS

I Introduction

Background

Close air support (CAS) is a combat air operation designed to provide flexible and sustained fire power against hostile targets in close proximity to friendly ground forces (Ref 1: Ch 2, 12). Close air support missions are conducted to thwart an enemy attack on friendly positions, help ground forces obtain the offensive, and provide cover for troop movements (Ref 24: Ch 4, 37). The value of close air support was first recognized during World War II, where timely application of airpower was often the decisive factor in the outcome of a ground battle.

CAS was also used extensively during the conflicts in Korea and Southeast Asia from which evolved much of the current U. S. Air Force air operations doctrine. This doctrine was conceived in an environment of minimal communications degradation and minimal hostile threat to airpower.

The Arab-Israeli War in 1973 was the first conflict to see the use of modern battlefield surface-to-air missiles (SAMs) and anti-aircraft artillery (AAA). These air defenses were extremely effective in limiting Israeli close air support operations, downing 35 airplanes on the first afternoon of

the war (Ref 11:20). The results of the Arab-Israeli War have forced a reexamination of the CAS mission especially as applied to the potential ground battle in Central Europe. NATO forces in Europe face military and environmental constraints which significantly limit close air support operations.

The first constraint is the threat posed to NATO air operations by a well equipped Warsaw Pact force. There are five Soviet ground armies in East Germany; each of which has approximately 1000 SAM and 1000 AAA systems (Ref 20:46). Specifically, a Soviet Army, consisting of three to four divisions distributed along a battle front 50 kilometers wide and 100 kilometers deep, would be protected by this mobile air defense system. The Warsaw Pact possesses a numerical advantage over NATO in tactical aircraft. The numbers of ground-attack aircraft are roughly equivalent, but the Warsaw Pact has a 2050 to 375 advantage in the number of air interceptors (Ref 21:24).

The CAS mission is further constrained by a substantial enemy electronic warfare capability. There are currently 1000 ground-based radar jammers in the Soviet inventory along with 1200 ground based communications jammers (Ref 11:4).

In addition to the air defense threat, CAS aircraft are highly vulnerable to destruction on the ground. NATO airbases are located well within range of both bomber aircraft and surface-to-surface missiles. Both of these delivery systems are capable of carrying conventional, nuclear, or chemical

munitions. Shelters are provided for the aircraft, but the aircraft would be useless if the runways and taxiways were destroyed.

Environmental constraints limiting CAS operations are weather and terrain. The weather in Central Europe, depending on the time of year, can be an important factor in air operations. Days during the fall, winter, and early spring are often characterized by a morning fog that persists until midday. Approximately one out of three mornings during these seasons will have visibilities less than one kilometer (Ref 8: Ch 13, 11). Cloud ceilings below 1000 feet can be expected 10 percent of the time during spring and summer, and as much as 28 percent of the time during winter and fall (Ref 8: Ch 13, 12). Low ceilings and poor visibility can result in CAS missions not having good enough weather to launch. Even if aircraft are launched, poor visibility in the target area can prevent target acquisition, and low cloud ceilings can force changes in weapons delivery parameters, reducing accuracy.

The last constraint to be considered is terrain. Most of the terrain in the American sector of West Germany consists of hills, forests, and numerous small towns. It is difficult for fast moving aircraft to visually acquire mobile targets like tanks, vehicles, and personnel in this kind of environment.

Aircraft and aircrews will be in short supply during the early stages of a war in Europe, requiring many sorties per aircraft. Since survivability of available aircraft is

essential to guarantee these high sortie rates, all air resources assigned to the CAS mission must be given a reasonable chance of surviving the opposing array of air defenses while performing their mission.

Problem Statement

NATO ground forces in Central Europe are confronted by 24 Warsaw Pact armor divisions, 27 other ground divisions, and 14 armor divisions available as ready reinforcements. These divisions include a total of 16,000 medium tanks, facing a NATO force of 6,615 tanks (Ref 20:46). These ground forces are protected from air attack by an air defense umbrella consisting of an overwhelming number of mobile SAMs and AAAs. Ground commanders will require close air support to combat this numerically superior force and stop its forward advancement.

The problem faced by the tactical air forces is how to best provide rapid and accurate firepower in support of the ground battle, while maximizing aircraft survivability. This is a significant problem considering the vulnerability of NATO air bases to enemy attack, the capability of Warsaw Pact air defenses, and the flying environment of Central Europe. The effectiveness of the CAS mission will depend heavily upon aircraft and aircrew capabilities and performance, weapons capabilities, and a mission structure based on communications, command, and control (C³).

Objective

The objective of this research effort is to examine some of the interactions present in the CAS mission and how they affect the targets-killed-to-aircraft-lost ratio. Aircraft exposure time to the different elements of the defensive array will adversely affect the aircraft kill-to-loss ratio.

Some of the primary factors that influence exposure time are aircraft airspeed, penetration distance behind the forward edge of the battle area (FEBA), weapons load, and the availability of enemy early warning (EW) radars. Since all of these elements have a direct influence upon aircraft exposure time, they will inturn influence the kill-to-loss ratio. The analysis, then, will be centered on these factors and their interactions. In addition to these interactions, a sensitivity analysis will be performed to determine the effect of elimination of certain threats from the model. Through this type of analysis some insight should be gained as to how aircraft airspeed, penetration depth, weapons load, EW availability, and elimination of particular threats will affect the aircraft kill-to-loss ratio for the CAS mission.

Literature Review

The specific purpose of this research, as outlined above, is to evaluate the kill-to-loss ratio of tactical aircraft versus enemy ground targets in a close air support environment, and how that ratio is affected by various factors. This effort comes under the general category of evaluating a tactical

aircraft's effectiveness and survivability in a low altitude, high threat environment. Numerous studies have been done in this general area, but each with a different specific objective in mind. Those studies and how they differ from this one are discussed in the following paragraphs.

Simulation Models. The studies and Analysis Section at Headquarters USAF uses several simulation models as tools for performing this type of analysis. Three of these models are the Blue Max Flight Path Model, TAC Zinger, and the TAC Warrior Theater Campaign Model (Ref 12).

The Blue Max Flight Path Model is designed to simulate the flight of an aircraft through a specific mission profile. Close air support is one of those profiles. The objective is to evaluate the performance capabilities of the aircraft or its weapons load under the specified conditions of the profile. The output from the model is a listing of X, Y, and Z coordinates of the aircraft at different points in the profile. These coordinates by themselves have no significant meaning relative to the effectiveness or survivability of the system. However, the output from this model is then used as input for the TAC Zinger Model, which will then provide the basis for a survivability analysis at each of the input coordinate sets.

TAC Zinger is a threat evaluation model which was originally developed at Georgia Tech University and now maintained by the Flight Dynamics Laboratory at Wright-Patterson Air Force Base. It models the engagement of

Soviet surface to air defensive systems against airborne targets. Using the data obtained from models such as the Blue Max, a complete survivability analysis can be accomplished. This model is extremely complex and took several years for development to its current status.

The TAC Warrior Theater Campaign Model is a comprehensive model that simulates an entire theater war. Close air support is only a small portion of this model. TAC Warrior is far beyond the scope of this research effort.

The objective of this research is to develop one model that will perform the combined functions of Blue Max and TAC Zinger. Obviously, in the time available for completing this research, the model will be based on a more simplified approach.

Flight Evaluations. Tactical Aircraft Effectiveness and Survivability in Close Air Support of Anti-Armor Operations (TASVAL) was a recently completed study designed to evaluate the effectiveness and survivability of aircraft in a close air support environment. The TASVAL data base will be used to study exposure of aircraft to air defense units, engagement of ground targets by aircraft, and estimated probability of kill resulting from these engagements (Ref 4:64).

Electronic Warfare in Close Air Support (EW/CAS) is a two phase test that is still in progress. The purpose of this test is to gather and analyze data concerning effects of electronic warfare in a CAS environment. Phase I, completed in March of 1980, was primarily concerned with communications

jamming, and its effect on CAS operations (Ref 4:66).

Both of these analyses were conducted as live exercises under controlled conditions. Their objective was the same as this research effort, although accomplished from a much different approach.

Previous Theses. Several other previous theses have concentrated on analysis of the low altitude, high threat environment of Central Europe. However, each of these dealt with a slightly different mission or a different aspect of the CAS mission.

A Wild Weasel Penetration Model was developed for the purpose of analyzing the threat suppression mission (Ref 2). The methodology used was simulation, and the model allows two wild weasel aircraft to penetrate into the FEBA area against the high threat environment expected to be encountered there. Their purpose is to attack and neutralize EW radars and threats so that an attack package of fighter bombers can penetrate through the FEBA to second echelon targets. The measure of merit is the number of fighters that reach the second echelon targets based on the suppression efforts of the Weasels.

Another research effort was a Survivability Study of a FLIR Equipped Fighter on a Night Penetration of a Soviet Army (Ref 18). Again, the methodology was simulation, and the model attempted to evaluate the survival capability of a tactical aircraft equipped with the LANTIRN system.

The aircraft penetrates the high threat environment at low altitude and high speed under night time conditions. The aircraft does not attempt to work in the FEBA area, but rather to penetrate through to the second echelon and deep interdiction targets. Various airspeeds and altitudes are evaluated. The overall objective is to see if the LANTIRN system will enhance night time penetration.

A third research project was a comparison between TAGSEM and Red Flag (Ref 14). TAGSEM is a computer simulation model that attempts to evaluate the effectiveness of air to ground systems in a tactical environment. Red Flag performs the same function except that it is a live exercise. This research performed a comparative analysis of data derived from the two sources, with an objective of seeing how well the two systems correlate.

The final thesis to be discussed is a Simulation Study of the Force Mix Problem in Close Air Support Operations (Ref 17). The purpose here was to compare an aircraft with very simple avionics to an aircraft with sophisticated avionics in the close air support role. Sortie loss rate is the effectiveness measure. The goal was to identify the force mix of these two aircraft that provided the lowest sortie loss rate. A major consideration in the sortie loss rate was the maintenance capability on each aircraft at the operating base.

Each of the above theses has the same general purpose as this research project, but the specific purpose of each

is different. This effort will attempt to analyze the effectiveness and survivability of an aircraft that remains in the FEBA area for an extended period of time. Previous efforts either dealt with aircraft that penetrated through the FEBA area as quickly as possible, or attempted to compare the operations of two different aircraft within the FEBA area. Additionally, several of the modeling techniques used in this thesis offer improvements over the approach used in previous theses. The first of these improvements is increased computer efficiency. This is accomplished through more effective use of the simulation language and its associated commands. This area will be discussed more fully in a later section. The second area of improvement deals with the dimensional aspect of the model. Previous theses were primarily two dimensional, while this model is completely three dimensional. This allows a more accurate evaluation of the effects of an aircraft changing altitudes through out the model.

One other area in which this thesis differs from previous ones is in the determination of when a SAM should launch its missile. The method used in the other models is to delay the missile launch, if possible, until a beam intercept can be accomplished. The rationale was that a beam intercept provides a higher radar cross section and thus a higher probability of kill. This approach is unrealistic for the close air support mission. Since the SAM operator does not normally know exactly where or when the CAS aircraft will release weapons, he must attempt to destroy the aircraft as soon as

possible. Thus the logic used in this model is to launch the missile as soon as a reasonable chance of successful missile intercept is achieved.

Scope and Limitations

In an attempt to limit the scope of this analysis, only a small section of the FEBA will be modeled. The opposing force along this sector of the FEBA will consist of only one division with its associated defenses. Only the radar controlled SAMs and AAA systems will be modeled. A typical division, such as the one considered here, will have a zone of advance that is 20 to 30 kilometers wide, with its main attack concentrated in a region that is 4 to 16 kilometers wide. The air defenses in this area will consist of 16 radar controlled AAA units, 20 radar controlled SAM A units, 5 SAM B radars, each controlling a battery of 4 SAM B units, and 3 radar controlled SAM C units (Ref 7).

To help stop the advancement of this division, CAS aircraft will be vectored to this sector of the FEBA. They will work under the direction of a FAC who will aid them in locating enemy targets and friendly forces. In reality, there may be more than one FAC working this area, and each would control his flight of fighters. For this analysis, only one FAC and a flight of two fighters will be modeled. The operation would be the same for other FACs in the area.

The model is developed in the context of the terrain of Central Europe, which consists primarily of thick forests and rolling farmland. The results from this analysis may

or may not apply to other environments with different terrain features. They can at least be used as starting guide lines when considering CAS in other terrain environments.

Maintenance capabilities such as sortie generation rate will be considered sufficient so that the required aircraft and weapons are available when needed. Consequently, the maintenance complex and base operations will not be modeled.

The weather, as such, will not be modeled. It is assumed that the weather in the battle area is good enough to perform CAS or the aircraft would not be in the FEBA area to begin with. Certainly, weather will be a major factor in restricting tactics and weapons employment as well as determining sortie loss rates. However, the goal here is not to evaluate the effect of weather on tactics or sortie rates, but rather to analyze the interactions between other factors of the CAS mission.

Tactics will not be directly evaluated since they could vary widely from aircrew to aircrew. However, basic tactical considerations will be reflected in the approach to weapons employment.

The kill-to-loss ratios computed in this model are to be used only as a tool for analyzing factor effects and interactions, and may not represent the true ratios of an actual combat situation.

Methodology

Depending upon the nature of the problem under consideration, the questions involved, and the time available

for study, the analyst must choose the most appropriate methodology for accomplishing the desired analysis. This methodology must provide flexibility and efficient, effective use of available resources. Since the objective of this analysis is to compare the kill-to-loss ratios of an aircraft in the close air support environment under varying airspeeds, penetration distances, EW capabilities, weapons loads, and threat levels, it was decided that the classical analytical techniques did not satisfy these requirements. The CAS environment is an extremely dynamic situation, and for this reason simulation was chosen as the appropriate methodology.

The simulation language used in this model is SLAM. The model will be a combination of continuous, network, and discrete event. With the model structured in this manner, extreme flexibility is built in, and the state conditions of each element in the model can be recomputed at very small time increments. This will facilitate the construction of a model that very closely represents the true dynamic system.

The simulation technique allows the important aspects of the system under study to be represented in mathematical form which is more amenable to investigation of varying conditions. The model is structured such that later modifications can be made with relatively little difficulty. By providing this feature, the model represents a flexible and responsive tool for addressing new and unanticipated questions relating to the close air support mission.

Summary

This chapter has provided an overview of the nature of the CAS mission, and the anticipated environment of Central Europe. Effective accomplishment of CAS operations in such an environment will not be easy. This thesis is an attempt to analyze, in some depth, several of the factors influencing the effectiveness of CAS operations. The factors to be analyzed are:

1. Aircraft airspeed.
2. Penetration distance behind the FEBA.
3. Aircraft weapons load.
4. The effect of enemy EW radars.
5. The number or density of defensive threats within the battle area.

Each of these factors will be analyzed at various levels to determine their main effects and interactions with the other factors. The measure of merit for the model will be the aircraft kill-to-loss ratio achieved. Through the analysis of these factors, some insight can be gained as to how to effectively employ the CAS resources. The following chapters will explain how this analysis was accomplished.

II Systems Structure

The close air support mission is highly structured and requires considerable coordination between ground forces and air forces. Since the CAS mission is flown in close proximity to friendly ground forces, an elaborate command, control, and communications (C³) system is required to insure timely and accurate targeting.

CAS Command, Control, and Communications

The requirement for close air support originates with the ground forces commander. The ground commander directs the Tactical Air Control Party (TACP) to request needed air support from the Direct Air Support Center (DASC). This request is monitored at higher echelons of command authority, and can be denied if aircraft are needed elsewhere or if Army firepower is deemed sufficient to counter the threat. The DASC initiates the planning and coordination required to process the CAS request, and in the absence of disapproval, orders the mission flown (Ref 24: Ch 4, 42).

CAS missions are generated through either preplanned or immediate requests. If the missions are preplanned, air assets are tasked against targets in advance, allowing valuable mission planning and aircrew briefing. However, the unpredictable nature of combat tends to produce immediate CAS requests, requiring responsive air forces. Responsiveness is achieved by diverting aircraft to the CAS mission from less critical

missions or maintaining CAS aircraft on alert status. This alert status can be either ground alert or airborne alert.

Once CAS aircraft are launched against a target, the C³ procedures are the same regardless of how the mission was generated. Aircraft are controlled by elements of the Tactical Air Control System (TACS). These control agencies may include the Airborne Command and Control Center (ABCCC) and the Airborne Warning and Control System (AWACS). These control agencies provide the CAS aircraft with radar vectors to a radar orbit point, current target weather information, and Forward Air Controller (FAC) radio call signs and frequencies (Ref 24: Ch 4, 42).

The CAS flights are then directed to the contact point (CP), where they establish radio contact with either a ground FAC (GFAC) or an airborne FAC (AFAC). The FAC provides the target location and description, as well as the positions of friendly ground forces. The CP is considered the beginning of the strike control area. From the CP the CAS aircraft proceed to the initial point (IP), where they enter the terminal control area. The FAC provides a magnetic bearing and flight time from the IP to the target to assist the attacking aircraft in target identification. Inside the terminal control area, the FAC must clear the flight to drop before munitions can be expended. Obviously the success of the CAS mission depends on extensive communications among the participants. A close air support structural model is illustrated in Figure 1.

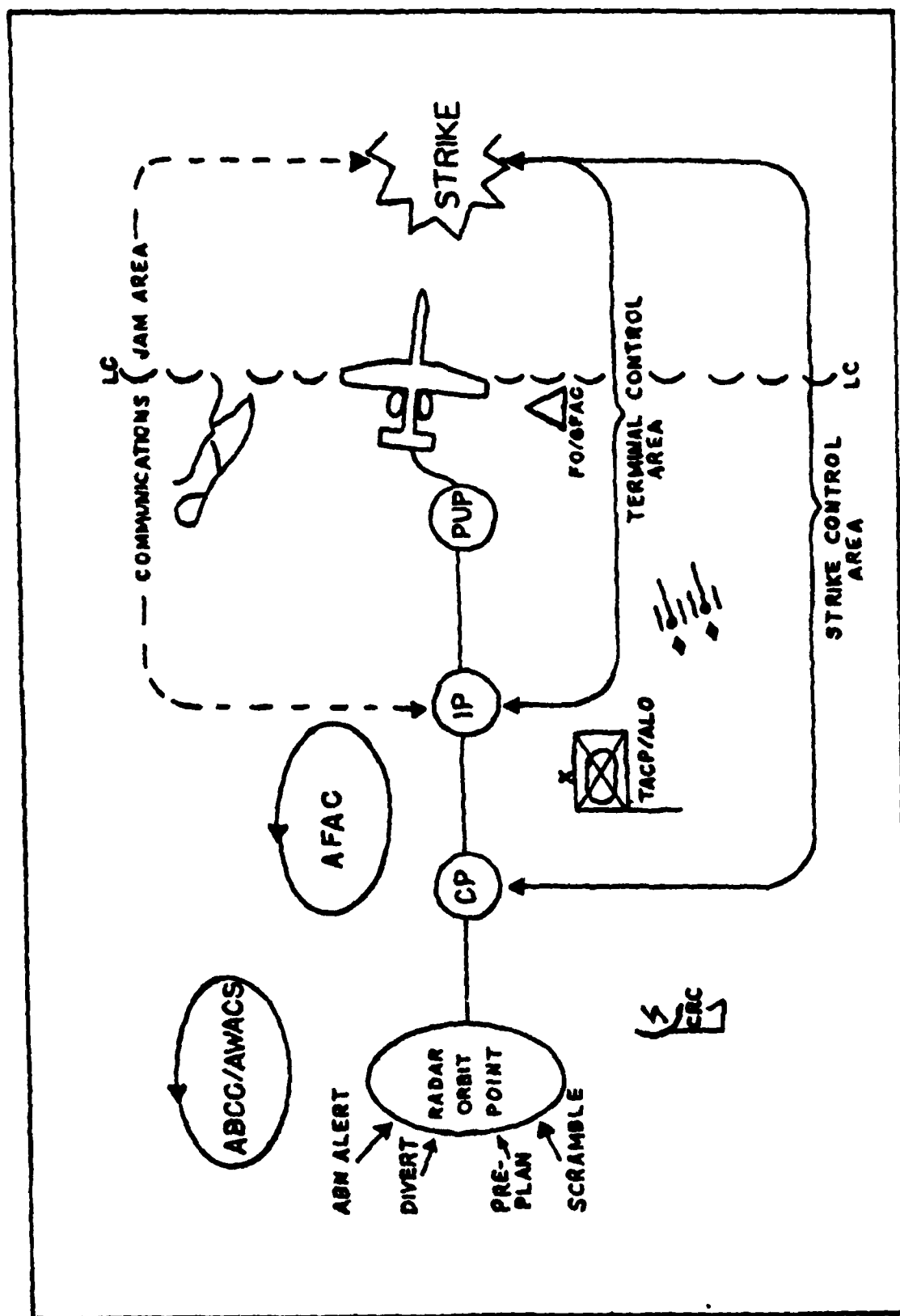


Fig. 1. CAS Structural Model (Ref 9)

Aircraft and Ordnance

The European environment requires aircraft and ordnance which can defeat the heavily armored threat facing US/NATO forces (Ref 9:13). The complexity of the CAS mission makes it difficult to design a weapons system capable of performing all the varied tasks of the mission. The suitability of a weapons system for the CAS mission is based on three major criteria. These are responsiveness, effectiveness, and survivability (Ref 21:3). These criteria are interrelated, improvement in one area often resulting in a degraded capability in another. For example, mission effectiveness could be improved by using slower aircraft capable of visual target identification. However, this would significantly reduce survivability. Response times could be shortened by employing vertical/short takeoff and landing (V/STOL) aircraft, operating from unimproved airfields close to the battle area. However, given present technology, this approach would reduce the load carrying capability of CAS aircraft.

Aircraft presently in the United States Air Force (USAF) inventory which are capable of performing the CAS mission include the A-10, F-4, and the F-16. The A-10 was designed specifically for close air support. Maximum employment airspeed for the A-10 is 385 knots at 5000 ft (Ref 9:12). Performance at this airspeed aids in the visual identification of enemy targets and improves the effectiveness of low altitude terrain following maneuvers. Redundancy of critical systems and armor shielding improves the survivability of the A-10

at low altitude and relatively slow airspeed.

The maximum weapons employment airspeed for the F-4 and F-16 is in excess of 500 knots. This increased airspeed capability improves survivability and responsiveness, but effectiveness suffers, primarily because of difficulty in target identification.

All three aircraft are capable of carrying ordnance suitable to the CAS mission. These weapons include general purpose bombs, cluster bomb units (CBU), Maverick missiles, and guns. Against the numerically superior enemy armor threat, the Maverick missile and the 30mm gun are the most effective. The Maverick missile can be employed by all three aircraft. The A-10 has an internally mounted 30mm gun, and both the F-4 and F-16 can carry an externally mounted 30mm gun pod. The Maverick missile is a desirable weapon to use in close air support because of its terminal guidance and stand-off capability.

Aircraft Electronic Countermeasures and Electronic Counter Countermeasures

Electronic Countermeasures (ECM) is defined as the development and application of equipment and tactics to deny the enemy the use of his electromagnetically controlled weapons (Ref 10:7). Close air support aircraft are equipped with a wide range of ECM equipment, including jammers, chaff, flares, and radar homing and warning receivers (RHAW). This equipment is essential given the sophistication of the hostile air defense threat.

Electronic counter-countermeasures (ECCM) is defined as that action necessary to insure the use of the electromagnetic spectrum by friendly forces (Ref 10:7). The ECCM capability of CAS air resources is enhanced by using radios and radio procedures designed to reduce the effect of enemy communications jamming. Also, airborne radars used in navigation and weapons delivery utilize ECCM techniques such as frequency agility and jittered pulse repetition frequency (PRF). ECCM is an important factor in the Central European theater because of the substantial Warsaw Pact investment in electronic warfare.

CAS Mission Profile

The execution of the close air support mission from inside the strike control area consists of three phases. These are ingress, attack, and egress.

Ingress. The ingress portion of the mission takes place between the CP and the pull up point (PUP). This is normally accomplished at low altitude to achieve the maximum benefit from terrain masking. Ingress altitudes as low as 100 feet are not unusual, depending on aircraft performance and pilot proficiency. From the IP to the PUP accurate aircraft navigation is critical. Navigation errors can result in a failure to locate the intended target or a failure to achieve the proper ordnance delivery parameters. Also, navigation errors lead to an increased exposure to the air defense threat.

The location of the PUP depends on the location of the target and the type of attack being performed. If the target

is located near the line of contact (LC) or forward edge of the battle area (FEBA), the PUP will be outside the range of many of the air defense threats. The further the ingress into hostile territory, the greater the exposure to air defense systems.

Attack. The attack phase of the mission begins at the pull up point. Factors bearing on the type of attack are angle off, dive angle, and release slant range for forward-firing ordnance like the 30mm gun and Maverick missile. The angle off pop-up attack is most often used. This particular attack is depicted in Figure 2. The target is approached such that a known number of degrees of turn is required to place the target directly in front of the aircraft. This required turn is called the angle off. The pop-up maneuver is accomplished to aid in target acquisition. Once the target is acquired visually, a turn is made to point at the target. The aircraft now has a certain dive angle and is located a given slant range from the target. If the PUP was determined correctly, and if navigation was adequate, the dive angle and slant range should be compatible with the type of ordnance being delivered.

Dive angle is not a critical parameter for forward-firing ordnance. However, shallow dive angles are effective in CAS because of the low cloud ceilings prevalent in Central Europe, and because shallow dive angles offer some terrain masking capability. A dive angle of five degrees would be a realistic

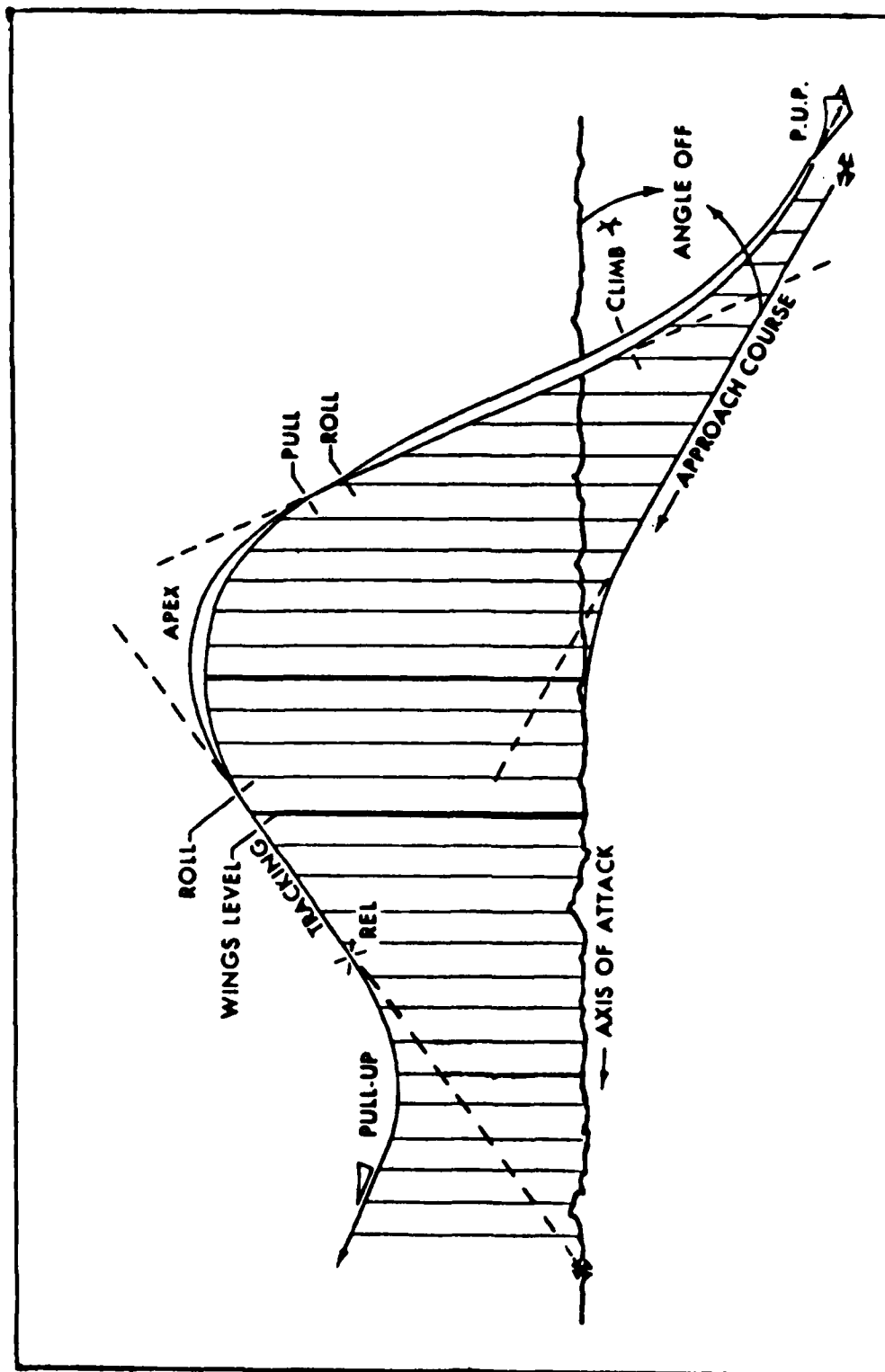


Fig. 2 Angle Off Pop Up Attack

value for forward-firing ordnance in Central Europe.

The desired slant range from the target depends on the ordnance being delivered. When employing the Maverick missile, the target must be acquired at a range where there is sufficient time to lock the missile seeker onto the target. Also, the firing range of the Maverick should take full advantage of the missile's stand-off capability, maximum effective range being in excess of two nautical miles.

When attacking with the 30mm gun, the attack must be initiated closer to the target. The gun is effective at a range of 6000 feet, but a more realistic firing envelope is 4500 feet to 1500 feet (Ref 6).

During the attack phase of the mission, if the target is not readily located, a descent back to low altitude and a reattack should be considered. Flying a predictable flight path, while visually searching for a target, increases the prospects of being successfully engaged by air defense forces.

Egress. Upon completion of the attack, flight out of the target area is accomplished at terrain-masking altitude. If a subsequent attack is to be made in the same target area an egress back to the IP for a reattack is appropriate. However, if all targets in a particular area have been destroyed or the ground forces wish to employ ordnance in the target area, an egress back to the CP is preferred. Communications between the FAC and CAS aircraft are less vulnerable to jamming at the CP. From the relative safety of the CP, battle damage assessments can be obtained, and the FAC can commit the aircraft

to another target if fuel and ordnance permit.

Soviet Attack Strategy

A Soviet field army consists of three to seven divisions, with each division divided into regiments (Ref 15: Ch 2, 8). The primary goal of Soviet offensive combat at any level is to destroy enemy forces and seize important terrain. Soviets try to realize this goal by rapid build up of required forces, echelonment of forces, massing forces in a decisive direction, and continuous development of the attack (Ref 15: Ch 3, 63). Paramount in this attack strategy is the desire to gain numerical superiority over a defending force at the main axis of attack. The desired force ratios are at least a three to one advantage in tanks, a six to one advantage in artillery, and a four to one advantage in infantry (Ref 15: Ch 3, 81).

The Soviets define the main axis of attack as a "specific zone of terrain between which the main efforts of the attacking forces are concentrated and the decisive blow is delivered" (Ref 15: Ch 3, 82). The location of the main axis of attack is chosen by the unit commander from within his assigned zone of advance, based on the enemy grouping of men and material (Ref 15: Ch 3, 83). The attack frontages of Soviet divisions and regiments are depicted in Figure 3. During the attack these units are protected by a sophisticated air defense network.

Air Defense Command, Control, and Communications

The Soviet air defense system incorporates concepts and

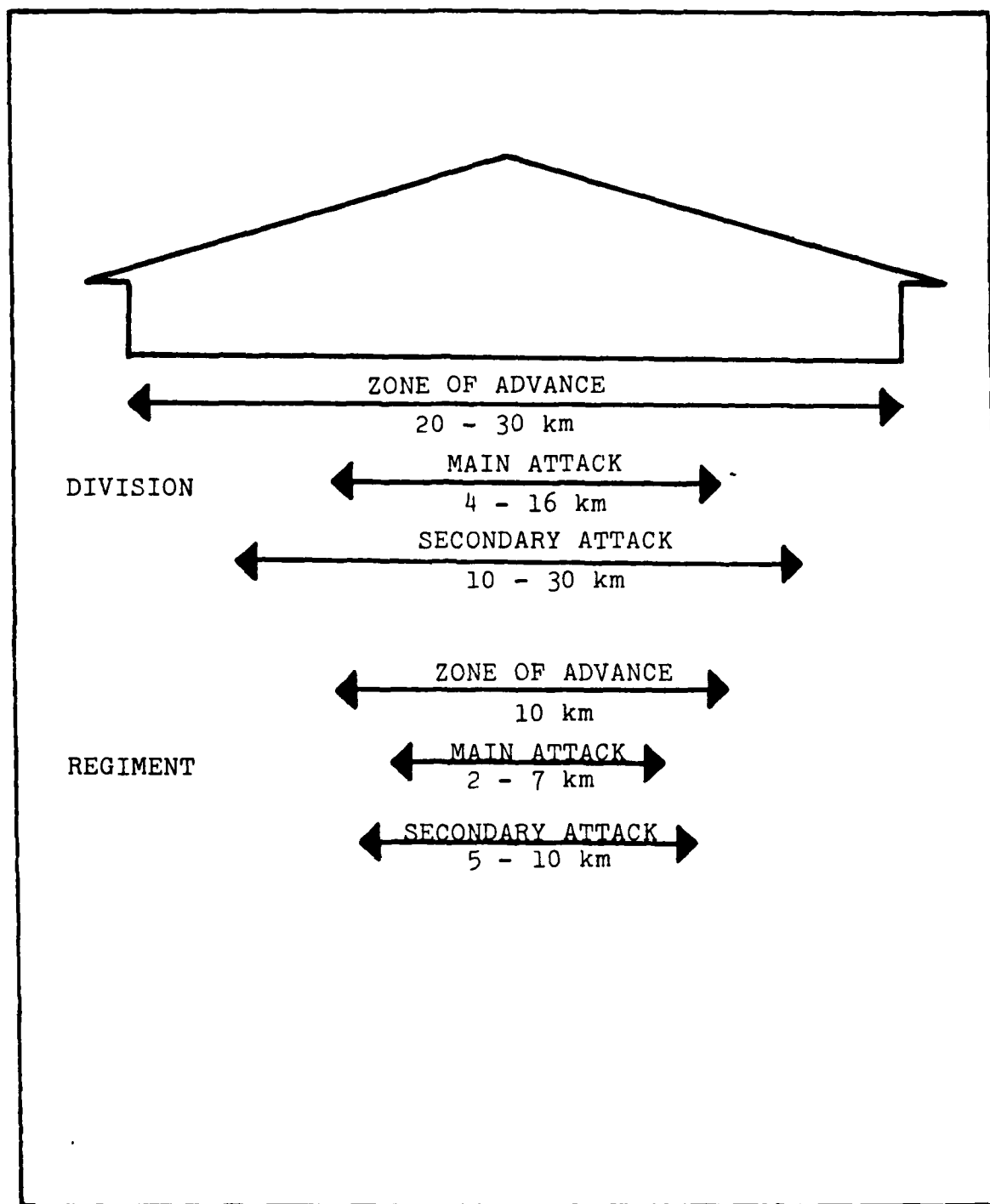


Fig. 3. Zones of Advance and Attack Frontages (Ref 15)

procedures that bring all available weapons into an integrated air defense effort. The field commander is responsible for the command and control of all air defense weapons. The unit air defense commander coordinates between subordinate and senior units to insure air defense coverage at all altitudes (Ref 15: Ch 5, 29). The most complex control problem is coordinating ground defenses with air interceptors (Ref 15: Ch 5, 29). For this reason, ground air defense is organized by zones, with aircraft being responsible for the air defense of flanks and areas beyond the maximum range of ground weapons. Therefore, once committed to an attack, close air support aircraft are unlikely to be threatened by air defense aircraft.

Enemy air defense gunners and missilemen are dedicated to their primary duty of air defense. They are well trained in both the operation of their weapons systems and communications. Early warning radar units and fire control radar units pass target information through an air defense communications network, sharing the data necessary to acquire and track target aircraft (Ref 9:44). This communication of information is essential to the effective command and control of air defense resources.

Air Defense Weapons Deployment

Air defense resources are assigned at various levels of command structure. At army level, air defense emphasis is on zone coverage at low/medium and medium/high altitudes (Ref 15: Ch 5, 22). Primary systems are the long range

surface-to-air missiles (SAMs), consisting of mobile varieties and those restricted to fixed locations. At division level, air defense units are employed as batteries in direct support of engaged motorized rifle or tank regiments. Air defense resources of a division are also used to protect division headquarters, critical support activities, and division rear areas. Mobile SAMs of medium altitude capability perform these roles (Ref 15: Ch 5, 22). At regiment level, air defense batteries are required to provide low altitude coverage for engaged motorized rifle and tank regiments. Air defense resources used in this role include mobile anti-aircraft artillery (AAA) of both radar and optically controlled varieties. Surface-to-air missiles, either mounted on vehicles or shoulder fired, employing infrared (IR) guidance, are also assigned at the regimental level (Ref 15: Ch 5, 25).

The exact placement of air defense forces on the battlefield depends on the judgement of the field commander (Ref 7). However, the placement of resources will comply with Soviet attack doctrine and the principle of overlapping air defense coverage. A threat structural model for the radar controlled air defenses included in this research effort is illustrated in Figure 4. This figure indicates the probable areas where each type of threat would be located. Threat density would be greater along the main attack axis and along lines of resupply from rear areas.

Air Defense Electronic Counter - Countermeasures

Modern air defense radar systems employ numerous ECCM

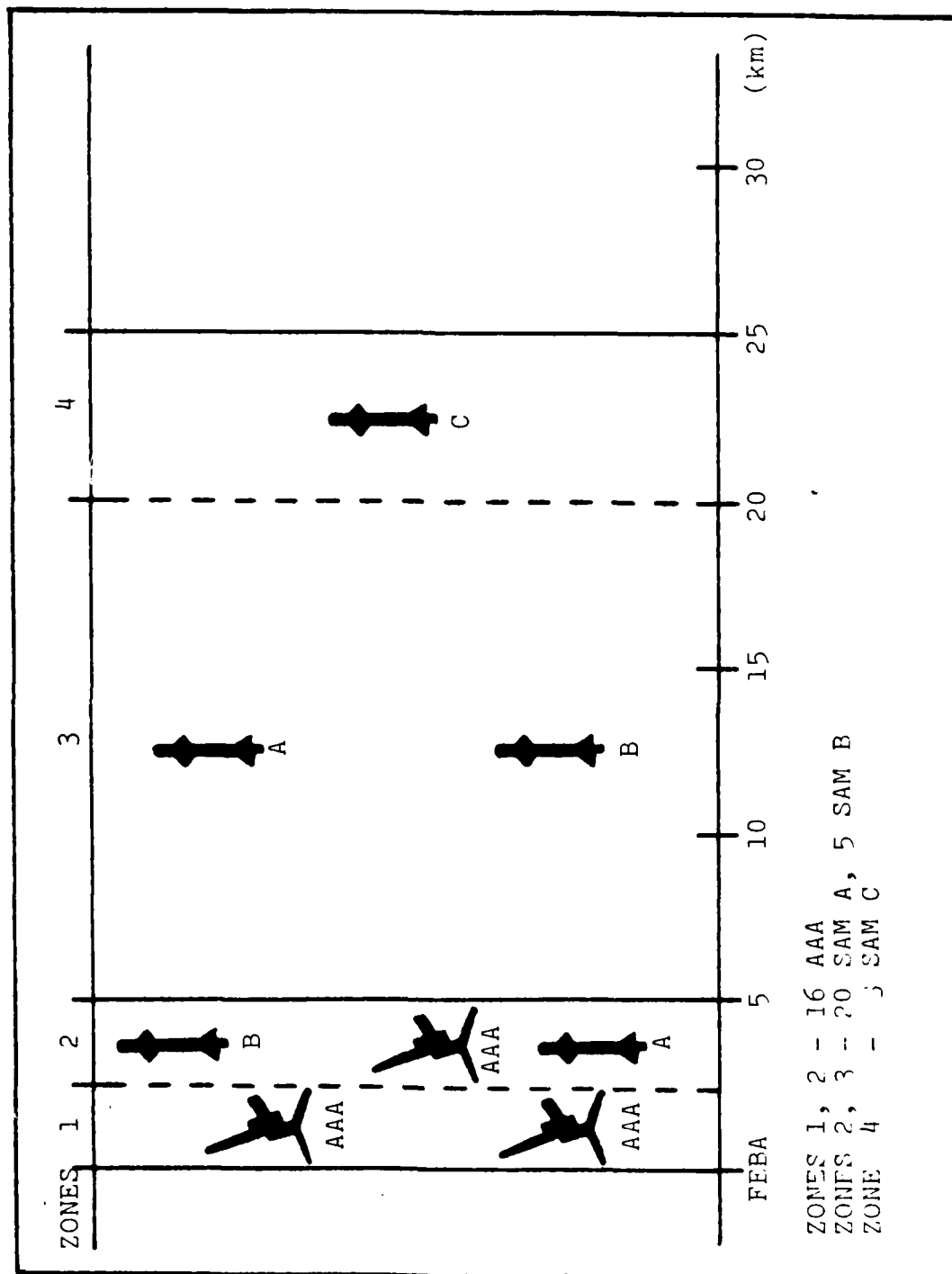


Fig. 4. Threat Structural Model

techniques. It must be assumed that Soviet systems are equipped with a significant ECCM capability. Side lobe blanking, monopulse, and frequency diversity are a few of the methods which could be used to counter a target carrying a noise jammer (Ref 10:231-239). Home-on-jam is a capability that many missiles have to guide on a jamming signal rather than on an aircraft radar return (Ref 10:232). Other techniques, such as optical tracking and triangulation by different radar sites, are effective against aircraft using ECM. Though ECCM may permit target tracking, weapons effectiveness can still be degraded. For example, home-on-jam allows a missile to track jamming signals in angle, but not in range (Ref 10:232).

Electronic warfare is a rapidly changing aspect of modern warfare. The ECCM capability of Soviet air defense systems should not be underestimated.

Air Defense Mission Profile

Target Acquisition and Tracking. The individual SAM and AAA systems depend on EW radars for assistance in target acquisition. The time required to acquire a penetrating aircraft would be increased without the information provided by the early warning radars. Once a target is detected by the acquisition radar, the tracking mode of operation must be engaged prior to weapons employment.

The maximum detection range of air defense radars against low altitude aircraft is primarily a function of terrain and

not radar performance characteristics. Even over flat terrain, an aircraft flying at 100 feet above ground level (AGL) would be inside a surface threat radar's maximum range before being detected above the horizon. Obviously terrain masking can be even more effective against acquisition and tracking radars.

Weapons Employment. Each air defense weapon has an effective envelope. This envelope is defined in terms of a minimum range, maximum range, minimum altitude, and maximum altitude. Maximum altitude is not a significant factor in close air support because of the low altitude flying operations involved. The maximum range is a function of the aerodynamic characteristics of the AAA round or SAM. The minimum range applies primarily to missiles, being a function of the time required for the warhead to arm. The minimum altitude is a function of missile guidance characteristics and missile behavior in proximity to radar ground clutter.

Air defense weapons employ two types of fusing, impact fusing and/or proximity fusing. The AAA being studied in this paper is limited to contact fusing. The SAMs are capable of detonating either on impact or in close proximity to the target aircraft. If an aircraft is to be destroyed, the missile warhead must detonate within a certain lethal radius.

The probability of a weapon destroying a target, once the decision is made to fire, depends on a number of independent probability factors. Foremost among these are probability of firing, probability of guiding, probability of fusing,

probability of a hit, and probability of a kill given a hit (Ref 3: Ch 7, 106). The individual firing the weapon can not consider all of these probabilities, but he must be sure the operational limits of the weapon are not exceeded.

Confounding Delay. After a particular aircraft has been engaged, there is a delay involved in preparing the system to acquire another target. This delay is called the confounding delay. This delay is due to the switch from the tracking mode to the acquisition mode of operation, as well as the time required to prepare ordnance for firing.

Terrain

The terrain of Central Europe can be both a help and a hindrance to close air support operations. The terrain features of central West Germany consist predominately of rolling farmland mixed with thick forests. Target acquisition can become extremely difficult in this terrain environment, especially for fast moving aircraft. In addition, the 30mm gun and the Maverick missile are line of sight weapons. Attaining such firing parameters is difficult in irregular terrain, and the air defense threat makes multiple attempts dangerous.

An advantage that the terrain offers CAS aircraft is the opportunity to use low altitude terrain masking. Proper use of terrain masking affords penetrating aircraft an element of surprise that can significantly increase survivability.

Weather

The weather in Central Europe is another important factor in air operations. As discussed in chapter one, a significant number of days during the year will be characterized by inadequate weather conditions for employment of CAS resources. Even when CAS aircraft are able to launch, many times the weather in the target area will be marginal for effective weapons employment. These conditions usually have the effect of forcing the aircrews to modify their tactics, often times resulting in decreased accuracy of weapons delivery.

Another major concern when flying in this type of weather is its effect on aircraft survival. To defeat a SAM, the pilot must visually acquire the missile and maneuver against it. Dismal weather conditions drastically reduce the visual warning time available to the pilot, and thus reduce his chances of defeating the missile.

Summary

Close air support is one of the most challenging missions assigned to tactical air forces. It is a highly structured mission, requiring extensive command, control, and communications. Aircraft performing the CAS mission must be well suited to the role of attacking in close proximity to friendly ground forces; and the ordnance carried aboard these aircraft must be capable of deterring the advance of enemy armored vehicles. The nature of the CAS mission dictates that air resources

be responsive, effective, and survivable during all phases of the mission profile.

The hostile air defense threat to air operations, often dismal weather conditions, and rugged terrain constrain the unlimited use of CAS in Central Europe. The negative impact of these constraints must be minimized if CAS is to remain a viable mission.

III Simulation Model

The close air support problem in Central Europe is modeled into the SLAM computer simulation program as shown in Appendix F. The model is constructed to incorporate the network, continuous, and discrete event features of the SLAM language. This combined model approach provides the most accurate representation of the CAS system and allows maximum model flexibility and responsiveness. The major portion of the modeling effort is accomplished through a series of FORTRAN coded subroutines integrated into the SLAM processing logic. The following subparagraphs will describe in detail the SLAM model and subroutines, and how each performs its specific function in the model. The assumptions necessary for this model are also delineated.

Assumptions

Any model of a real world system, whether it is a simulation model or otherwise, must be designed with certain assumptions incorporated. The assumptions for this model are listed below:

1. Aircraft enter the system with sufficient fuel to stay in the target area for 30 minutes.
2. The FAC will work only two aircraft at one time. Other FACs are available for additional fighters.
3. The fighters will work separate targets in the battle area while under the FAC's control.

4. The weapons employed by the fighters will be Maverick missiles and the 30mm cannon.
5. Enemy communications jamming can only delay the FAC briefing, it cannot make communications impossible.
6. Aircraft will maintain their assigned combat airspeed throughout the profile.
7. Both ingress and egress of the target area is accomplished using low altitude terrain masking.
8. Fighters will attempt to employ the Maverick as the primary weapon to provide greater stand-off range.
9. A 30 degree angle off pop is planned to allow easier target acquisition.
10. Apex altitude during the pop will be planned to give a 5 degree dive angle during attack.
11. Ingress and egress will be made with an average G loading of 2 G's.
12. Only one hot firing pass is accomplished per attack.
13. Either the gun or the Maverick can be fired during an attack, but not both.
14. Maverick lock-on and firing requires 1 G flight.
15. Maverick lock-on time will average 8 seconds, following a uniform distribution between 5 and 11 seconds.
16. The minimum lock-on range for the Maverick is 4000 feet. If not locked on by that range, a transition will be made to a gun attack.
17. The average G loading during a gun pass is 3 G's.
18. The average Maverick PK is .85 (Ref 5).

19. The minimum firing range for the gun is 1500 feet (Ref 6).
20. The gun will be fired in a one second burst, expending either 35 or 70 rounds per firing pass depending on the selected firing rate.
21. The direction of the attack roll-in will be planned, based on the geometric relationship between the IP and the target, to allow the turn to egress heading to be made with minimum exposure to defensive systems.
22. All roll-ins will be made with 4 G's.
23. All turns of 20 degrees or more will be made at 4 G's. Turns of less than 20 degrees will be made at 2 G's.
24. After roll-in, if the target is not within 30 degrees or 3NM of the nose of the aircraft, the pass is aborted.
25. If the achieved dive angle exceeds the planned dive angle by 15 degrees or more, the pass is aborted.
26. If the target is not killed on an attack, the aircraft must reattack.
27. Electronic countermeasures jamming is employed by the aircraft against the threat tracking radars.
28. Radar cross sections are computed based on a theoretical aircraft (Ref 18:20).
29. After completing a firing pass, the aircraft will turn in the shortest direction to a 270 degree egress heading.

30. The egress heading will be 270 degrees until outside of the FEBA area. A heading correction will then be made to return to the IP or CP.
31. Fuel checks are made in the safe area. Determination to re-enter the target area is based on estimated remaining fuel when arriving at the IP or CP and weapons load.
32. Only one division of threats is incorporated in the model.
33. The distribution of the threats is at the discretion of the division commander. This distribution will be controlled by the model.
34. If early warning (EW) radar is available, the acquisition and tracking time for the threat follows a uniform distribution. Otherwise, the acquisition and tracking time is set at its maximum value.
35. If the aircraft is at its ingress/egress altitude, a defensive threat will not fire until it has a precomputed PK of .5 or greater. If the aircraft is performing its pop up or maneuvering, the required firing PK is reduced to .1.
36. No more than 30 percent of the AAAs or SAMs are allowed to engage a particular aircraft at any one time. This restriction is imposed by command and control elements.
37. Threat ammunition depletion is not considered.
38. An engaging threat will fire when the aircraft is

within the engagement envelope and all parameters are met.

39. A threat can fire only once at an aircraft and must then go through a confounding delay.
40. A threat can engage only one aircraft at a time.
41. A threat can continue to track an aircraft inside minimum range.
42. If the aspect angle between the aircraft and the threat is greater than 90 degrees and the aircraft is outside of the engagement envelope, the threat will disengage.
43. A threat will not attempt to track an aircraft after it reaches the safe area.
44. The weather for this model is 3NM visibility with a 1500 feet ceiling as a minimum.

Combined SLAM Modeling

Real world systems can usually be described as either discrete change systems, continuous change systems, or combined discrete - continuous change systems (Ref 19:402). These classifications depend upon how the system in question changes with time. In a discrete change system, the system status changes at isolated points in time, while in a continuous change system, the system status undergoes a continual change with respect to time (Ref 19:403). Because of the dynamic nature of the close air support system, it is necessary to use a combined discrete - continuous model. Additionally, since a CAS aircraft follows a prescribed sequential pattern

of actions or events as it proceeds through its mission profile, the network modeling technique can be effectively incorporated into the model. Consequently, the full power of the SLAM language has been incorporated into this combined network, discrete event, continuous model of the CAS system.

The primary purpose of the network is to route the CAS aircraft through its mission profile. The SLAM network is illustrated in Appendix A. The network begins by creating a flight of two aircraft at time zero. The flight proceeds to a GOON node where the two aircraft are separately routed to ASSIGN nodes where each aircraft is given a set of attributes. Included in this set of attributes are aircraft call sign, initial fuel supply, initial gun and Maverick loads, and airspeed. Global variables are used in the assignment of attributes to provide model flexibility. In addition to those listed above, other attributes are assigned to keep track of certain occurrences later in the model. A complete listing of attributes is given in Appendix E. The aircraft are then rejoined as a flight and routed to another GOON node. Two paths are taken from this node. One path routes an entity to event 14 which activates the defensive threat portion of the system. This entity is cycled back through event 14 at one second intervals. Based on the value of the global variable XX(I+57), event 14 determines when each aircraft departs the IP in the network. Once the aircraft has departed the IP, then event 14 calls subroutine THREAT at one second intervals, which causes the threat radars to

search for the aircraft. The second path which emanates from the GOON node routes the two aircraft to a QUEUE node where the aircraft receive their target briefings. Since the FAC briefs each aircraft separately, aircraft number two waits in the queue until aircraft number one has received its briefing and departed the CP for the IP. Aircraft number two then receives its target briefing. The time spent receiving the target briefing is represented by a uniform distribution with minimum and maximum values of 30 seconds and 120 seconds respectively. After departing the queue and CP, the network routes each aircraft through a series of event nodes that represent different action points in the profile, until the aircraft is eventually shot down or returns to the CP or IP. This portion of the network is very dependent upon subroutine EVENT which will be explained in a separate subparagraph. COLCT nodes and ACCUMULATE nodes are positioned in the network to collect the number of targets killed, aircraft lost, and aircraft returning home and to provide statistics for each case.

The continuous aspect of the model is achieved through subroutine STATE. Subroutine STATE utilizes difference equations to update aircraft position, heading, and altitude at one second intervals. Thus, a continuous movement of the aircraft through the system is achieved. Subroutine STATE is explained in detail in a later subparagraph.

The discrete portion of the network is accomplished through events 15, 16, and 17. These events are discretely

scheduled from different subroutines based upon certain conditions being satisfied. These events will be discussed in detail in the subparagraph for subroutine EVENT.

In an effort to increase efficiency, this model takes a slightly different approach than that taken by some previous theses. Those theses used SLAM commands such as COPY and REMOVE for file manipulations. The approach taken in this thesis is to use the SLAM pointer system commands and ULINK for file manipulations. This approach greatly reduces the computer time required to perform the task. Another time saving approach used in this thesis is to eliminate the use of DETECT nodes. By allowing the appropriate event to compute the time required to perform a particular maneuver and assigning this time to the appropriate activity, the DETECT node Runge-Kutta integration technique is avoided, thus reducing the amount of computer time required. These modifications significantly increase model efficiency.

Coordinate System

To aid in the understanding of the model and in the computation of relative positioning between the different elements in the model, the battle area is represented by an X, Y, Z coordinate system. Under this convention, the X-coordinate represents the east-west direction, the Y-coordinate represents the north-south direction, and the Z-coordinate represents altitude. The unit of measurement along each axis is kilometers. The area is constructed such that the

FEBA extends north and south along a line with an X-coordinate of 15. The CP is located 15 kilometers west of the FEBA at coordinates (X, Y, Z) equal to (0,16,0). The IP can be located anywhere between the CP and the FEBA. For this scenario the IP coordinates are (8,16,0). The main attack occupies a front along the FEBA that is 10 kilometers wide, extending from Y=10 to Y=22. The zone of advance is 24 kilometers wide, extending from Y=4 to Y=28. Within this zone of advancement, the Y-coordinates of the targets and threats are normally distributed with a mean of 16 kilometers and a standard deviation of 5 kilometers. The X-coordinates of the targets are uniformly distributed between 15 kilometers and 25 kilometers. Fifty percent of the AAA units have an X-coordinate of 16 kilometers and 50 percent have an X-coordinate of 17 kilometers. The X-coordinates for the SAM As and SAM Bs are uniformly distributed between 20 and 30 kilometers while the SAM Cs have an X-coordinate of 35 kilometers.

With each model component defined by coordinates, subroutine GEOM can then be called to determine the geometric relationship between any two of them. Figure 5 illustrates the X, Y plane of this coordinate system.

File Structure

The SLAM file structure utilized in this model is outlined in Appendix D. File 1 is used to maintain the aircraft radar cross section (RCS) data associated with various aspect angles. File 2 is used to maintain each threat entity and its associated

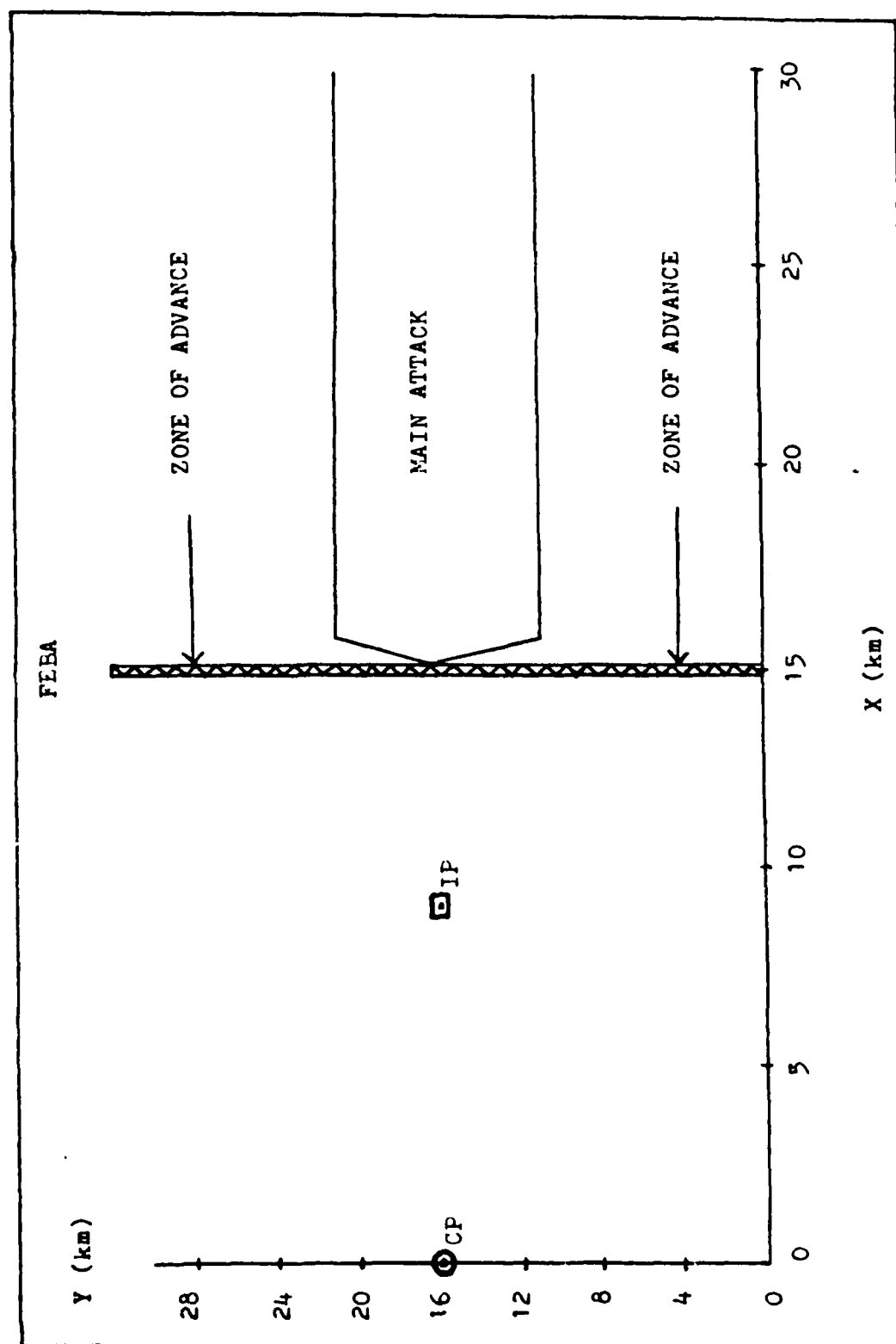


Fig. 5. Coordinate System

attributes. These entities are grouped within the file according to type of threat. The attributes assigned to each of the entities are listed in Appendix E. File 3 represents the FAC briefing queue and file 4 is the SLAM event calendar. The SLAM pointer system and file manipulation commands are used to manipulate these entities within each file.

In addition to the threat entities in file 2 and the two aircraft entities in the model, a threat/aircraft entity is created each time a threat is committed against a particular aircraft. The attributes for these entities are a combination of the threat attributes and the aircraft attributes, and a listing of these attributes is included in Appendix E. These threat/aircraft entities are manipulated on the event calendar, file 4. For example, if a particular entity is to be removed from the event calendar, the SLAM pointer is first positioned to the first entity in the file. The pointer is then sequentially stepped through each entity until the entity with the appropriate attributes is found. The SLAM command ULINK can then be used to remove the entity from the file.

Subroutine INTCL

Subroutine INTCL is used to assign initial values to the model parameters. These values represent the starting conditions for each simulation run.

The aircraft radar cross section data is initialized into an array through the use of a data statement. This two

dimensional array assigns a radar cross section value, expressed in decibels per square meter, to each value of the aspect angle between the aircraft and the threat radar. The aspect angle is measured in five degree increments from 0 degrees to 180 degrees. Four RCS values are assigned to each aspect angle. These RCS values represent the cross section seen by the AAA, SAM A, SAM B, and SAM C radars respectively at the associated aspect angle. These array values are then filed into file 1 which can be manipulated by the model to extract the desired RCS for the appropriate threat and aspect angle.

The global variables are initialized to the starting conditions for the model. These global variables are used extensively throughout the model to provide maximum flexibility. The definition of each global variable is provided in Appendix C.

Since this is a continuous SLAM model, the initial values of the state variables must be established. Each aircraft is assigned an initial value for its X-coordinate, Y-coordinate, altitude, and heading based upon the values of certain global variables. The definition of each state variable is provided in Appendix B. Additionally, the turn rate and climb rate for each aircraft is initialized to zero.

The final function of subroutine INTCL is to create and position each of the threats and to assign the attributes associated with each threat. Attribute 1 is used as a call sign or identification number to designate each individual

threat. Attribute 2 is used to identify the type of threat. The AAA, SAM A, SAM B, and SAM C units have attribute 2 values of 1, 2, 3, and 4 respectively. The X and Y coordinates of each threat are assigned from the appropriate distributions as discussed previously in the coordinate system subparagraph. The remaining attributes are used to specify the operating parameters of the threat. These threats and their associated attributes are then filed in file 2. A complete listing of the attributes and their definitions is included in Appendix E.

Subroutine STATE

The function of subroutine STATE is to define the dynamic equations for the state variables used in the model. After initialization of the starting conditions, the SLAM executive routine calls subroutine STATE at prescribed time intervals to obtain new values for the state variables (Ref 19:349). For this model difference equations are used to compute the new values for the state variables at time intervals of one second. Subroutine STATE will also be called at intermediate times if the state variable values are required by an intervening event. The state variables used in the difference equations are listed in Appendix B.

The aircraft heading is computed using the equation

$$SS(I+6) = SSL(I+6) + DTNOW(TRATE(I)) \quad (1)$$

where I is the aircraft call sign, and TRATE(I) is the aircraft

turn rate measured in degrees per second.
 Condition equations are included to maintain the aircraft heading between the limits of 0 degrees and 360 degrees.

The aircraft altitude is computed using the equation

$$SS(I+4) = SSL(I+4) + DTNOW(ARATE(I)) \quad (2)$$

where ARATE(I) is the aircraft climb or descent rate measured in meters per second.

A condition equation is included to prevent the aircraft from descending below a minimum altitude of 30.48 meters.

The X-coordinate of the aircraft is computed using the velocity vector equation

$$SS(I) = SSL(I) + DTNOW(\sqrt{(XX(I+9))^2 - (ARATE(I))^2}) \\ (\cos(90.0 - SS(I+6))) \quad (3)$$

where XX(I+9) is the aircraft velocity in meters per second.

The Y-coordinate of the aircraft is computed using the velocity equation

$$SS(I+2) = SSL(I+2) + DTNOW(\sqrt{(XX(I+9))^2 - (ARATE(I))^2}) \\ (\sin(90.0 - SS(I+6))) \quad (4)$$

Through the use of these equations, the exact aircraft positioning and performance parameters are available at any particular time within the model.

Subroutine GEOM

Subroutine GEOM is used to compute the geometric relationships between the aircraft's present position and any other point of interest within the coordinate system.

The entering dummy arguments for GEOM are:

YP - the Y-coordinate of the point of interest
YA - the Y-coordinate of the aircraft's position
XP - the X-coordinate of the point of interest
XA - the X-coordinate of the aircraft's position
HEAD - the current heading of the aircraft
ALT - the current altitude of the aircraft

The dummy arguments for the output parameters of GEOM are:

BEAR - the magnetic bearing from the aircraft to the
point
ASPECT - the angle between the nose of the aircraft
and the point
GR - the ground range from the aircraft to the point
SR - the slant range from the aircraft to the point

Other parameters computed by GEOM are:

$$YDIS = YP - YA \quad (5)$$

$$XDIS = XP - XA \quad (6)$$

$$\theta = \text{ABS}(\text{ATAN}(XDIS/YDIS)) \quad (7)$$

Figure 6 illustrates these geometric relationships defined by the relative positioning of the aircraft and the point of interest.

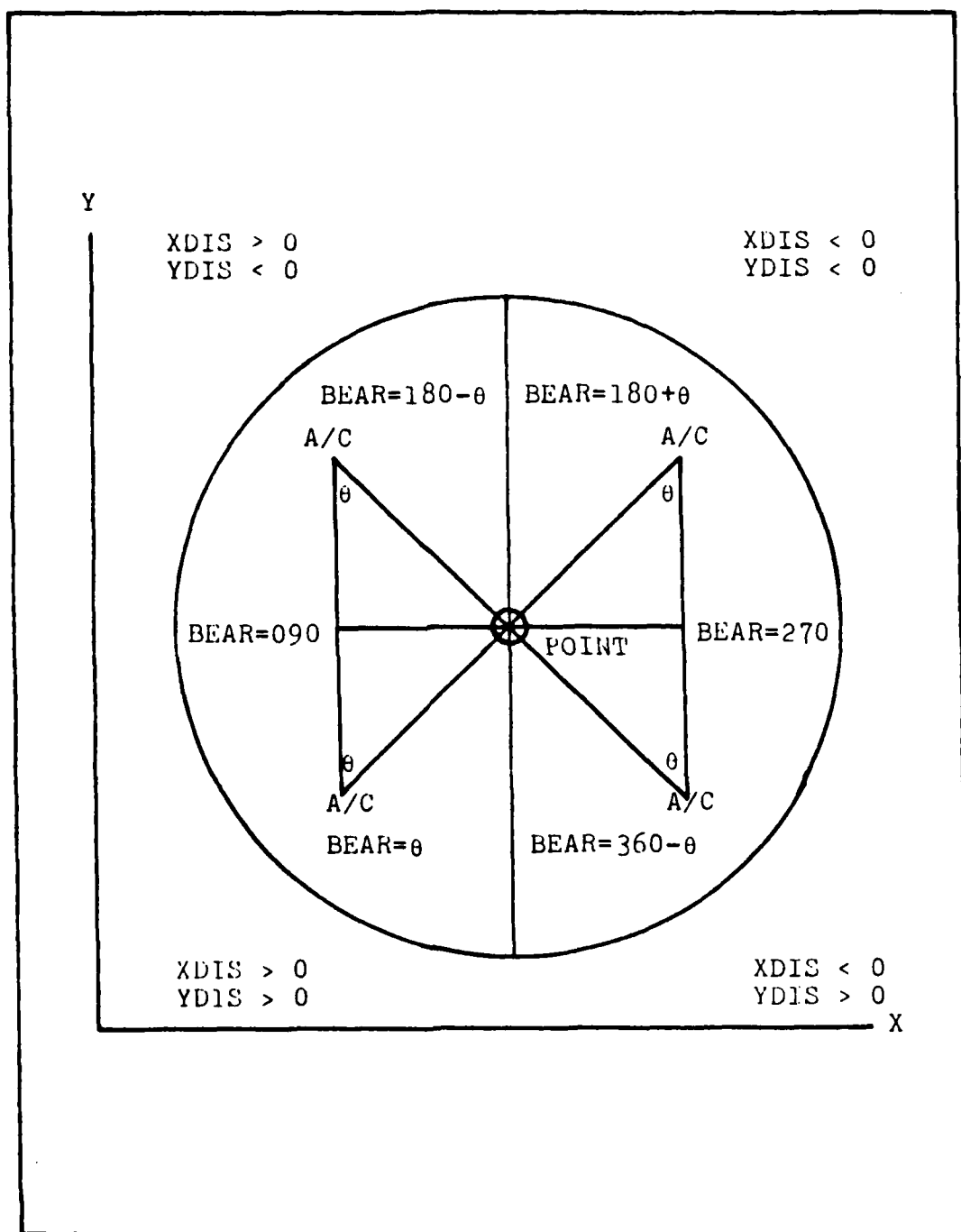


Fig. 6. Geometric Relationships

When subroutine GEOM is called from within the program, the dummy arguments are replaced by the appropriate state and global variables.

Subroutine MASK

Because of the low altitude ingress of the aircraft and the hilly, forested terrain of Central Europe, the aircraft will probably not be detected immediately. This aspect is incorporated into the model by subroutine MASK. It translates the aircraft altitude and distance from a threat into a series of probability equations based upon the European terrain by applying curve fitting techniques to the data illustrated in Figure 7 (Ref 18:44). Each curve in Figure 7 is broken into segments that can be approximated by straight lines. The straight line equation is then derived for each of these curve segments as follows:

$$Y = mx + b \quad (8)$$

where Y is the probability of radar line of sight,

m is the slope of the line,

x is the ground range between the threat and the aircraft,
and

b is the Y intercept.

When subroutine MASK is called, the entering parameters are aircraft altitude and ground range, which was computed from GEOM. From these parameters a line segment from the appropriate curve is selected and the probability of radar line of sight is computed. This output parameter from MASK is then used

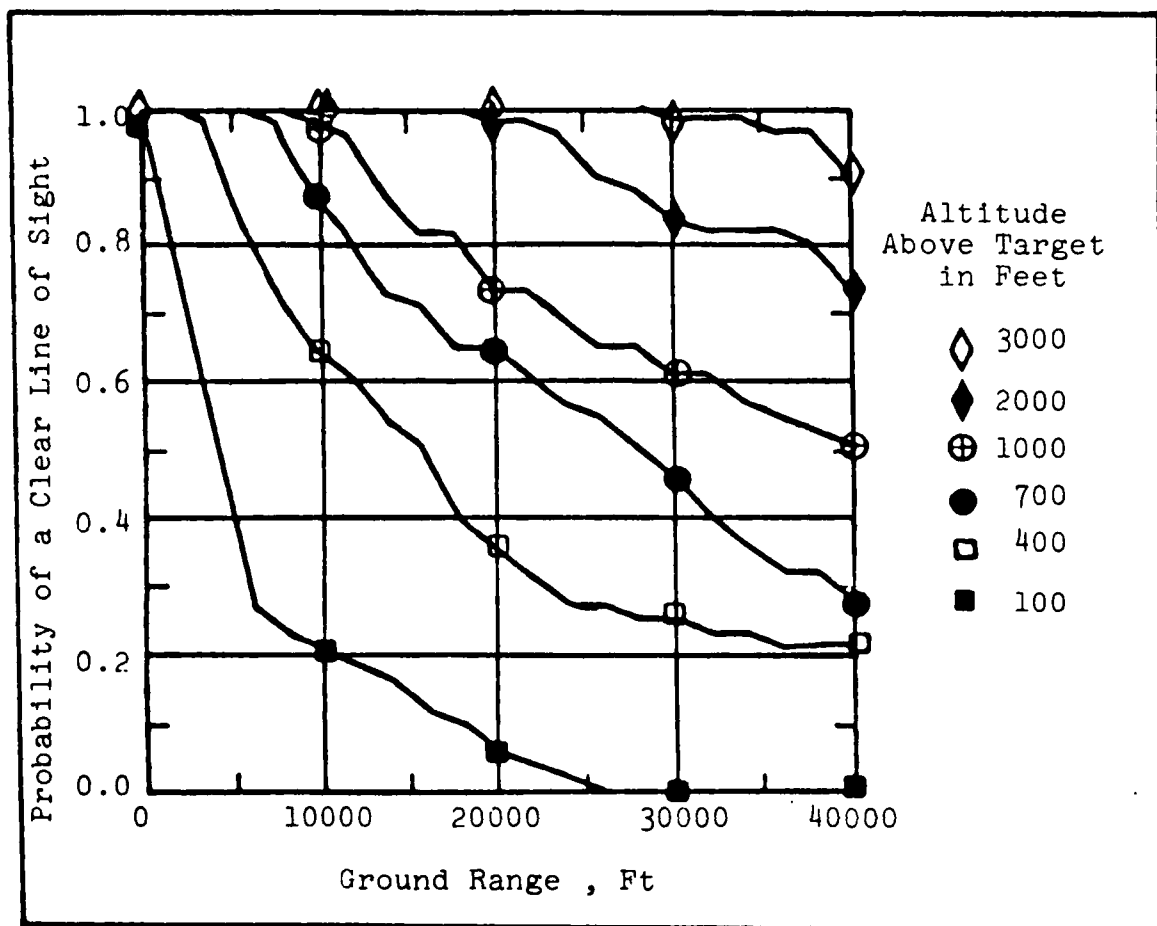


Fig. 7. Terrain Blockage Data for Rolling Farmland
With Thick, Close-in Forests

in conjunction with a random number generator to determine if the aircraft is detected. Subroutine MASK is called every second for each uncommitted threat.

Subroutine THREAT

Subroutine THREAT is called from event 14 at one second intervals when certain conditions are met, and is responsible for committing the various threats against the aircraft. It is also responsible for controlling the number of threats that are paired against each aircraft.

When subroutine THREAT is called, the first action accomplished is to set a pointer to the first entity in the threat file, file 2. The pointer is then sequentially stepped through each entity in the file. If the threat being considered is not already paired against an aircraft, and if the maximum number of engaging threats of that type has not been reached, then subroutines GEOM and MASK are called. From these two subroutines the geometric relationships and the probability of aircraft detection are computed. A random number generator is then used to determine if the aircraft is detected. If the aircraft is detected, the threat is paired against that particular aircraft and all the threat attributes are placed into an array for easy access. If the aircraft is not detected, or if the threat is already paired, or if the number of engaging threats has reached its maximum value, then the pointer advances to the next threat and the process is repeated until all the threats have been tested.

The parameters which affect the engagement capabilities of each threat are maintained as attributes within the threat file. When the threat is paired against an aircraft, these attributes are placed into an array and become associated with a particular aircraft/threat combination. Since these attributes play a major role in determining the results of an engagement, they will be explained further in the following paragraphs.

The aircraft in this model carries a jammer which radiates power uniformly in all directions in the hemisphere below the aircraft. The effective radiated power (ERP) of this jammer against each threat is maintained as a threat attribute and is shown in Table I, expressed in watts and decibels (db) (Ref 18:18).

TABLE I
EFFECTIVE RADIATED JAMMER POWER
AGAINST DEFENSIVE SYSTEMS

<u>THREAT</u>	<u>ERP</u>
AAA	1694w (32.3 dbw)
SAM A	914w (29.6 dbw)
SAM B	914w (29.6 dbw)
SAM C	914w (29.6 dbw)

The ERP of the jammer affects the range at which a target tracking radar can acquire, track, and employ weapons against a target.

The electronic parameters of the tracking radar also affect the range at which a target can be acquired, tracked, and engaged. These parameters are the transmitted power (P_r) of the radar and the gain (G_r) of the radar antenna. Both parameters are maintained as threat attributes in the decibel form and are shown in Table II (Ref 18:18).

TABLE II
AIR DEFENSE SYSTEM ELECTRONIC PARAMETERS

<u>THREAT</u>	<u>P_r</u>	<u>G_r</u>
AAA	50.9 dbw	40 db
SAM A	50.0 dbw	43 db
SAM B	53.0 dbw	41 db
SAM C	50.0 dbw	42 db

In addition to the electronic parameters, each threat has an associated engagement envelope. This envelope consists of minimum and maximum engagement ranges and altitudes. These parameters are a function of the missile capabilities as well as the radar capabilities, and will be maintained as attributes. The average velocity of the missile also plays an important part in determining if an intercept can be made for a given set of conditions. Finally, after the intercept is completed, the lethal radius (LR) of the missile warhead must be considered. The lethal radius can be defined as the maximum distance from the warhead detonation at which sufficient damage will occur to the target to result in a kill. All of these parameters are shown in Table III. The distances and altitudes are

TABLE III
AIR DEFENSE SYSTEM ENGAGEMENT PARAMETERS

<u>Threat</u>	<u>Min Altitude</u>	<u>Min Range</u>	<u>Max Range</u>	<u>Avg. Missile Velocity</u>	<u>Lethal Radius</u>
AAA	0 m	0.0 m	2990 m	-	-
SAM A	45 m	2038.0 m	10200 m	525 m/sec	22.0 m
SAM B	15 m	4076.6 m	22250 m	599 m/sec	26.2 m
SAM C	305 m	7968.0 m	74150 m	759 m/sec	43.6 m

measured in meters while the missile velocity is measured in meters per second (Ref 2:39).

All the threats in the model must go through distinct stages in order to engage an aircraft. The first stage is the target acquisition and tracking stage. This stage begins when a clear radar line of sight to the target exists. Each system will vary in the amount of time it takes for the radar to search for and acquire the target and to achieve a lock on. The second stage begins after a tracking solution has been achieved and the missile is launched. This stage involves the missile fly out time to complete the intercept. This time is a function of target range, heading, airspeed, and missile velocity. The final stage is the confounding delay. This delay represents the time necessary to get the missile launchers and radars ready to engage the next target. The acquisition and tracking times and the confounding delays are maintained as attributes and are shown in Table IV (Ref 18:41).

TABLE IV
AIR DEFENSE SYSTEM TIME CONSTRAINTS

<u>Threat</u>	<u>Acquisition and Tracking</u>		<u>Confounding Delay</u>
	<u>Min</u>	<u>Max</u>	
AAA	6 sec	25 sec	30 sec
SAM A	10 sec	23 sec	30 sec
SAM B	17 sec	38 sec	30 sec
SAM C	12 sec	26 sec	15 sec

In the operation of the model, if EW radars are available, then the acquisition and tracking time is selected from a uniform distribution with the minimum and maximum values as shown in Table IV. If no EW is available, then the maximum acquisition and tracking time is used.

Each of the attributes discussed above will contribute to the probability of kill computation outlined in subroutine PKILL. This subroutine will be discussed next.

Subroutine PKILL

The purpose of subroutine PKILL is to compute the probability of kill for each AAA and SAM shot and to update the number of threats engaged on the aircraft based upon the success or failure of the shot. PKILL is called from discrete events 15 and 16, whose functions will be discussed later. The first task of PKILL is to determine the type of threat, AAA or SAM, that is engaging the aircraft. Having done this, it then computes a probability of kill for the appropriate threat and engagement conditions. If the computed probability of kill satisfies the minimum launch requirement then the threat launches a weapon at the aircraft. Otherwise, control is returned to the main program and the aircraft resumes its flight path for one second. PKILL is then called again and a new PK is computed. This process continues until a weapon is launched or until the aircraft is no longer in the engagement envelope.

The range at which a target tracking radar can detect an aircraft is a function of the radiated power of the radar,

the antenna gain, the radar cross section of the aircraft, the effective radiated power of the jammer, and the jamming-to-signal (J/S) ratio at which the radar operator can burn through the clutter on his scope and lock-on to the target (Ref 10:102). All of these parameters enter into the probability of kill computation for the SAM systems. However, since the maximum engagement range of the AAA is much less than the maximum detection and tracking range of the radar, these parameters do not enter into the AAA PK computations. The PK computations for the AAA and SAM systems are illustrated in the following paragraphs.

To determine the PK for the AAA, the projectile velocity at impact must first be computed. This is done using the equation

$$V_f = V_i e^{-(\rho C_d A R / (2m))} \quad (9)$$

where

V_f = final velocity of projectile

V_i = initial velocity of projectile (930 m/sec)

ρ = air density (1.225 kg/m³)

C_d = drag coefficient (.38 average for AAA)

A = cross sectional area of projectile (.0004155 m²)

R = intercept range in meters

m = projectile mass (.195 kg)

(Ref 3: Ch 2, 46).

When the above values are substituted into equation (9), it

reduces to

$$V_f = 930 e^{-.0004965(R)} \quad (10)$$

Once the final velocity of the projectile is known, then the time of flight (TOF) of the projectile can be computed using the equation

$$TOF = \frac{2m}{\rho C_d A} \left(\frac{1}{V_f} - \frac{1}{V_i} \right) \quad (11)$$

where

TOF is measured in seconds and all other values are as previously defined (Ref 3: Ch 2, 46).

Substituting in the appropriate values gives

$$TOF = 2014.46 \left(\frac{1}{V_f} - \frac{1}{V_i} \right) \quad (12)$$

The average vulnerable area (A_v) for the aircraft in this model is 55.65 ft² or 5.17 m². This is based on an average viewing aspect of a total projected area of 265 ft² and a 21 percent vulnerable area (Ref 2:61).

The dispersion of the AAA rounds about the aim point is assumed to be 20 mils for the combat situation presented in this model (Ref 2:61). This angular dispersion represents a one sigma standard deviation and can be represented in terms of R, intercept range, by the equation

$$\sigma = 20R \quad (13)$$

where R is measured in kilometers.

The single shot probability of kill can now be computed by

$$PKSS = \frac{A_V}{2\pi\sigma^2 + A_V} \exp\left\{-.5 \left[\frac{(9.8g \text{ TOF}^2)^2}{2\pi\sigma^2 + A_V} \right]\right\} \quad (14)$$

where g = the aircraft G loading, and

$$A_V = 5.17m^2 \text{ (Ref 2:61).}$$

The overall PK of the gun depends upon the PKSS and the number of rounds fired by the AAA. This model assumes an average firing burst of 100 rounds. This would provide a reasonable projectile density around the target without overheating and damaging the gun barrels. So, the final PK calculation of the AAA becomes

$$PK = 1.0 - (1.0 - PKSS)^{100} \quad (15)$$

or the probability of AAA kill is 1 minus the probability of the aircraft surviving 100 single round shots (Ref 2:62).

The probability of kill for a SAM engagement depends upon the lethal radius of the missile and the circular error probable (CEP) associated with the SAM system. The LR has been previously defined and is maintained as a threat attribute. The CEP can be defined as the error associated with the distance measured between the desired and actual points of impact. In more precise terms, it is a sphere around the target aircraft within which 50 percent of the missiles fired under a given set of conditions will detonate (Ref 2:42). Thus, PK can be computed by the equation

$$PK = 1.0 - .5(LR/CEP)^2 \quad (16)$$

Before this equation can be used, the CEP must be calculated for the particular missile and the engagement conditions. This can be done by using the following equation:

$$CEP = \sqrt{A(J/S)R^2 + B(J/S) + C} \quad (17)$$

where A, B, and C = constants for each type SAM,

R = range from launch to target, and

J/S = jamming to signal ratio (Ref 2:43).

The values for the A, B, and C constants are shown in Table V (Ref 18:25-30).

TABLE V
CONSTANTS FOR CEP COMPUTATIONS

<u>THREAT</u>	<u>A</u>	<u>B</u>	<u>C</u>
SAM A	.000000325	1890.0	25.0
SAM B	.000000710	2200.0	58.0
SAM C	.00000562	2500.0	232.0

The value of R is determined by subroutine GEOM for each intercept. J/S depends upon the range from the radar to the aircraft, the ERP of the jammer, the electronic parameters of the radar, and RCS of the aircraft. The RCS of the aircraft varies according to the aspect at which the radar is viewing the aircraft and the operating frequency of the radar. The AAA and SAM A radars will see the same RCS at a given aspect angle because of the closeness of their operating frequencies. The SAM B and SAM C radars see the

same RCS for the same reason. Table VI shows these RCS values for various aspect angles (Ref 18:20). A 0 degree aspect represents a head-on view and a 180 degree aspect represents a tail view.

With all this information, then the J/S can be determined by the equation

$$J/S = \frac{(ERP)(4\pi)(R^2)}{P_r G_r (RCS)} \quad (18)$$

where all terms are as previously defined (Ref 2:45). Converting all of the terms to the decibel equivalent gives the following equation:

$$\begin{aligned} (J/S)_{db} = & (ERP)_{db} + (11)_{db} + 2(R)_{db} - (Pr)_{db} \\ & - (Gr)_{db} - (RCS)_{db} \end{aligned} \quad (19)$$

This computation yields a J/S expressed in db. This ratio must now be converted back to the numeric form to be used in the CEP equation. This conversion is accomplished by

$$J/S = 10^{((J/S)_{db})/10} \quad (20)$$

The terms are now in the proper format to apply equation (17) to obtain the CEP of the SAM system for the given conditions. Having computed the CEP, equation (16) can then be applied to compute the PK of the SAM for the given engagement.

TABLE VI
AIRCRAFT RADAR CROSS SECTIONS (dbm²)

<u>ASPECT</u> <u>(DEGREES)</u>	<u>AAA</u> <u>SAM A</u>	<u>SAM B</u> <u>SAM C</u>
0	8.20	3.60
5	6.70	.40
10	1.90	2.55
15	3.48	3.03
20	.85	1.70
25	3.95	2.50
30	5.20	10.65
35	-1.20	7.95
40	1.70	3.45
45	6.35	3.70
50	3.10	- .95
55	1.00	- .65
60	1.90	- .95
65	.25	.05
70	8.19	8.45
75	13.43	14.55
80	16.70	16.35
85	16.08	16.00
90	24.38	24.98
95	19.23	19.95
100	16.58	15.75
105	5.83	9.20
110	9.50	8.73
115	6.20	3.65
120	7.85	2.33
125	4.28	3.13
130	3.48	3.03
135	4.35	-1.08
140	3.90	-2.60
145	6.00	.50
150	5.23	.55
155	6.93	.43
160	2.95	.58
165	4.73	6.38
170	9.93	6.53
175	13.50	8.85
180	15.05	9.48

Subroutine EVENT

Subroutine EVENT represents the heart of the simulation model. It routes the aircraft through the CAS network, performing each required maneuver and the associated decisions for that maneuver at separate EVENT nodes. It controls interactions of all the elements of the CAS system by calling subroutines GEOM, MASK, THREAT, and PKILL at the appropriate times. It also controls the scheduling of the discrete events at the proper time. Subroutine EVENT can be divided into six different areas relating to the various phases and aspects of the mission. These six areas are discussed in the following paragraphs.

Ingress. The ingress phase of the CAS mission is simulated in events 1, 2, and 3. Event 1 represents the CP and is used to assign a specific target to the aircraft. The X and Y coordinates of the target are selected from the appropriate distributions as discussed earlier. The possibility of more than one target in the same area as the assigned target is controlled by a random number generator. After receiving the target coordinates, the aircraft is given a combat airspeed, a heading, and a time to fly to the IP.

After leaving the CP, the aircraft flies to the IP, represented by event 2. The function of event 2 is to compute the attack geometry and the heading and distance to the pull up point (PUP). Since the X and Y coordinates for both the present position and the target are known, the heading and distance to the target can be computed. However, the planned

attack calls for the aircraft to arrive at its final attack parameters with the target displaced 30 degrees from the nose of the aircraft and at a slant range of either 1 or 2 nautical miles (NM). This will allow the pilot better visibility for acquiring the target and put him at a sufficient range to employ the weapon. Based on this requirement, a geometric modification must be made to the computations to determine the heading and distance to the PUP. This attack geometry is illustrated in Figure 8. The first parameter determined is the desired slant range from the aircraft to the target measured from the point at which the aircraft begins tracking the target. This slant range will be 2 NM if there are Maverick missiles on board and 1 NM if the gun is the only weapon available. Having determined the desired slant range, the next step is to determine the apex altitude in the pop up maneuver. This apex altitude is a function of the desired dive angle and slant range. Thus, the apex altitude can be computed by

$$APEX = [\sin(XX(46))] \text{ FINAL} \quad (21)$$

where $XX(46)$ = the desired dive angle (5 degrees), and

$FINAL$ = the desired slant range.

Knowing the apex altitude and the original aircraft altitude, the distance that the aircraft must climb can be computed by

$$XX(I+55) = APEX - SS(I+4) \quad (22)$$

where $SS(I+4)$ is the aircraft altitude.

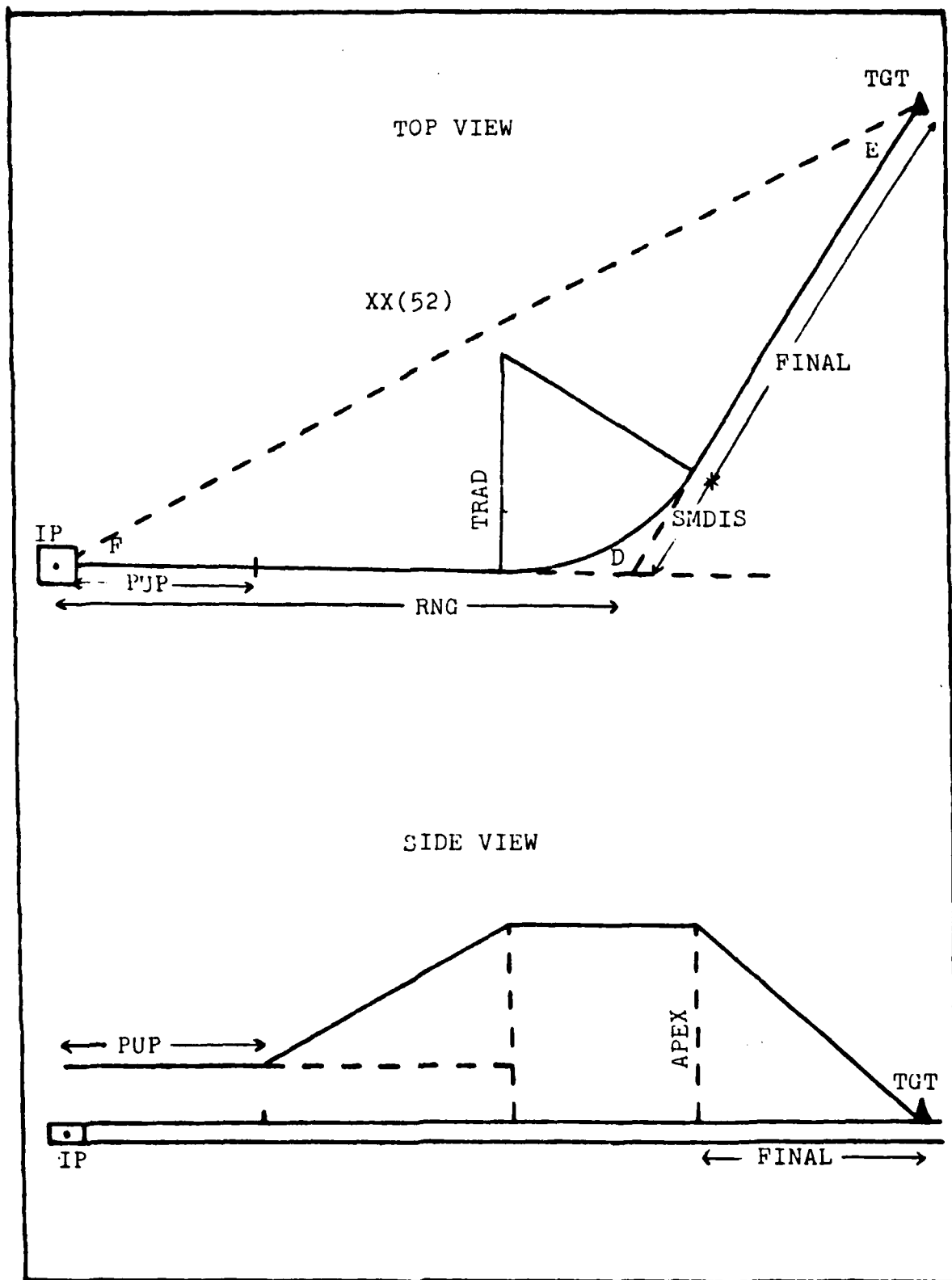


Fig. 8. Attack Geometry

The aircraft turn radius can be computed by

$$\text{TRAD} = \frac{v^2}{g(9.8)} \quad (23)$$

where v = aircraft velocity in meters/sec, and
 g = aircraft G load.

Using the law of sines trigonometric relationships as well as information obtained from subroutine GEOM, each of the angles D, E, and F, and each side of the triangle in Figure 8 can be computed. From this information the distance from the IP to the PUP can be computed by

$$\text{PUP} = \text{RNG} - \text{SMDIS} - (\text{XX}(1+55)/\text{TAN}(\text{XX}(46)+5)) \quad (24)$$

where RNG and SMDIS are as depicted in Figure 8.

The heading to the PUP can now be computed by either adding the value of angle F to 90 degrees, or subtracting it from 90 degrees depending on the relative position of the target to the IP. Navigational errors in airspeed and heading as well as defensive reactions enroute to the PUP may cause the pilot to miss his preplanned parameters. To incorporate these errors into the model, the actual heading and distance flown to the PUP are represented by normal distributions. The heading distribution has a mean equal to the computed desired heading and a standard deviation of c e degree. The distance distribution has a mean equal to the computed distance and a standard deviation of 5 percent of the computed distance.

Event 3 represents the aircraft departing the IP towards the PUP. This event keys the threats to begin their radar

search for the aircraft and sets the ingress acceleration factor at 2 G's, which represents the average G loading on the aircraft during ingress.

Attack. The attack phase of the CAS mission is simulated in events 4, 5, 6, 7, 8 and 9. Event 4 represents the PUP and is used to climb the aircraft to the apex altitude that was computed in event 3. The required climb angle to put the aircraft at the proper preplanned attack parameters is determined by adding 5 degrees to the value of the planned dive angle. Using this computed climb angle and the XX(I+55) variable, vertical distance to climb to reach the apex altitude, the appropriate time to climb and climb rate are computed. These values are then used by the model to fly the aircraft to the apex altitude.

After arriving at the apex altitude, event 5 represents the roll-in maneuver performed by the aircraft to align itself with the target. The climb rate is set equal to zero and a G load of 4 G's is assigned to the aircraft during the turn. A turn radius and a turn rate are computed based on 4 G's and the aircraft velocity. Since this is a 30 degree angle-off attack, the aircraft is turned through an angular measurement of 30 degrees. The direction of turn is determined by the relative position of the target with respect to the IP. For example if the target is farther north than the IP, then the roll-in direction will be a turn to the left.

After completing the turn, event 6 calls subroutine GEOM to determine the bearing and range from the aircraft to

the target. If the relative bearing is greater than 30 degrees, then the pilot has missed his preplanned parameters to such an extent that the attack must be aborted. Also, if the slant range exceeds 3 NM, then the target can not be visually acquired and the attack is aborted. If these parameters are not exceeded, then the attack is continued. A new turn radius, turn rate, and G loading are computed to cause the aircraft to make a final heading correction towards the target.

After completing the heading correction to the target, event 7 establishes a dive angle that points the nose of the aircraft directly at the target. This allows the pilot to track the target for weapons employment. If the computed dive angle exceeds the planned dive angle by 15 degrees or more, then the aircraft is too steep for safe weapons delivery and the attack is aborted. Also, if the slant range is less than the minimum firing range for the weapons load, then the attack must be aborted; otherwise, the attack is continued. The next step is to determine which weapon to use. If there is a Maverick available and the slant range is greater than the minimum firing range for the Maverick, then a lock-on time is computed from the appropriate uniform distribution. The predicted slant range at the expiration of the lock-on time is then computed. If the aircraft will still be outside of minimum firing range, then the Maverick is employed. If any of these conditions are not satisfied, then the gun is employed if there is ammunition available; otherwise, the

attack is aborted.

Event 8 represents the actual firing of the selected weapon and computes an appropriate PK. The PK for the Maverick will be .85 for each shot (Ref 5). The PK for the gun will be computed in the same manner as described for the AAA PK computation. However, the particular values for the computations will be somewhat different. The initial velocity of the projectile is the aircraft velocity plus the muzzle velocity of 1005.84 m/sec (Ref 6). The dispersion of the 30mm gun is 5 mils (Ref 6), and the average vulnerable area, A_v , of a typical tank size target is 12.24 square meters based on 60 percent of the average presented area (Ref 13). The number of rounds fired by the gun is based on the firing rate and the length of burst. A one second burst with a firing rate of 4200 rounds/minute are assumed for this model. After the PK is computed, a random number generator is used to determine if the target is killed.

Event 9 represents the attack recovery maneuver. The aircraft descends to its egress altitude and turns in the shortest direction to an egress heading of 270 degrees. The G loading is reset to an average of 2 G's for the egress.

Egress. Events 10, 11, 12, and 13 represent the egress portion of the mission. Event 10 computes a time and distance to maintain the 270 degree egress heading to return to the safe area. This safe area is defined as 3 kilometers west of the FEBA.

After arriving in the safe area, event 11 turns the aircraft either towards the IP or the CP, depending upon whether the same target area must be reattacked or if a new target assignment must be made. Subroutine GEOM is used to determine the bearing and distance from the aircraft to the point. A turn rate and radius are computed and the aircraft is turned to the bearing computed in GEOM. However, because of the turn radius, the aircraft will not be pointed directly towards its destination. An iterative process of heading corrections is performed until the aircraft heading is within one degree of the bearing to the point. This aircraft turn logic is illustrated in Figure 9.

Event 12 computes the flight time to the IP or CP and checks the aircraft fuel to see if another attack is feasible. If the fuel supply is sufficient for another attack, then the weapons load is checked to see if any weapons remain on board. If fuel and weapons exist, then the aircraft re-enters the ingress portion of the network; otherwise, the aircraft leaves the system and returns to home base. If the aircraft leaves the system to return home, then all references to this aircraft are removed from the event calender. The final function of event 12 is to stop the threats from searching for the aircraft in the safe area. The threats that have already acquired the aircraft but have not yet fired at it, are disengaged from the aircraft and sent to the confounding delay. The event calendar is then cleared of all references to these aircraft/threat entities, and the threats become

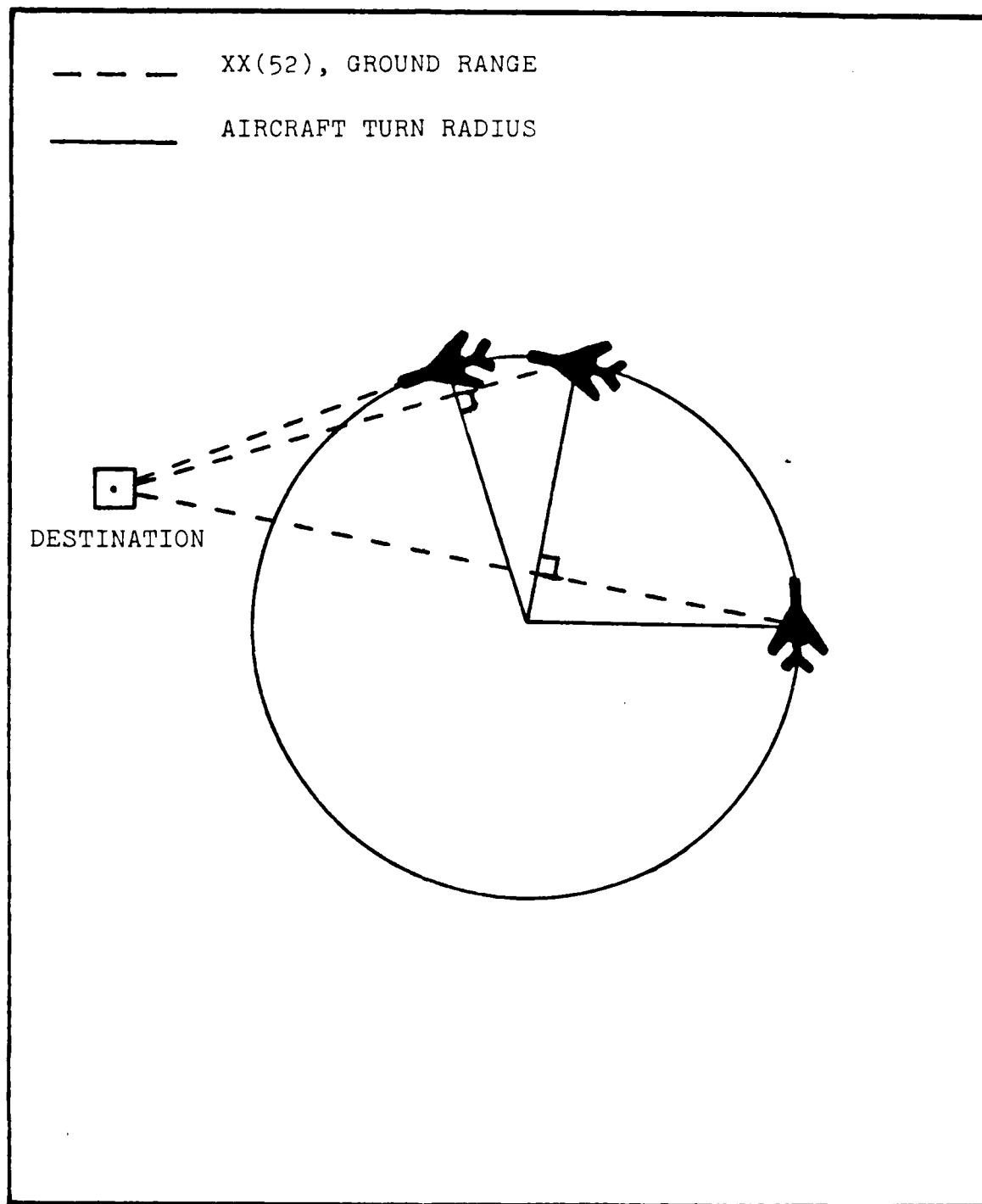


Fig. 9. Aircraft Turn Logic

eligible to engage another aircraft at the end of the confounding delay.

Event 13 reinitializes the state variables for the aircraft to begin its next attack.

Threat Search. Event 14 is responsible for calling subroutine THREAT which puts the AAA and SAM radars into the search mode. When an aircraft departs the IP, an entity with the same call sign as the aircraft is created and routed to event 14. This entity keys the threats to search for the aircraft with the same call sign. Event 14 is rescheduled at one second intervals for this entity as long as the aircraft remains in the system and outside of the safe area. This, in effect, causes each uncommitted threat radar to search for the aircraft once every second. The global variables XX(I+70) and XX(I+72) represent the respective number of AAA units and SAM units committed on each aircraft. When a threat radar locates the aircraft and is committed to that aircraft by subroutine THREAT, the value of the appropriate global variable is increased by one. The total number of threats committed against the aircraft is then computed as the sum of these two global variables. So long as this total number of committed threats is less than the maximum number allowed to simultaneously engage an aircraft, and the aircraft remains outside the safe area, then subroutine THREAT will continue to be called at one second intervals for that aircraft.

Discrete Events. Events 15, 16, and 17 are the discrete events for this model. They do not automatically occur in the

network event sequence, but must be individually scheduled to occur at the desired time.

Event 15 can be scheduled from subroutines THREAT or PKILL, or from within event 15. Its first function is to call GEOM to determine the geometric relationships between the aircraft and the threat. If the aircraft is determined to be in the engagement envelope of a AAA unit, then PKILL is called to determine the feasibility of firing immediately or whether to delay firing until a higher PK is achieved. If the threat is a SAM and the aircraft is within the engagement envelope, then event 15 computes the missile time of flight and the projected intercept point for an immediate launch. This intercept geometry is illustrated in Figure 10. Computation of the required information depends upon the ratio of the aircraft velocity to the missile velocity. This ratio is computed by the equation

$$VRAT10 = XX(I+9)/ATR1B(11) \quad (25)$$

With this ratio, the values of angles A and B can be computed in the following manner:

$$A = \text{ASIN}(VRAT10 \times \text{SIN}(XX(51))) \quad (26)$$

$$B = 180.0 - (XX(51) + A) \quad (27)$$

where $XX(51)$ is the aspect angle.

The projected missile time of flight can now be computed by the equation

C = XX(51)
D = TOF(ATR1B(11))
E = XX(53)
F = TOF(XX(I+9))

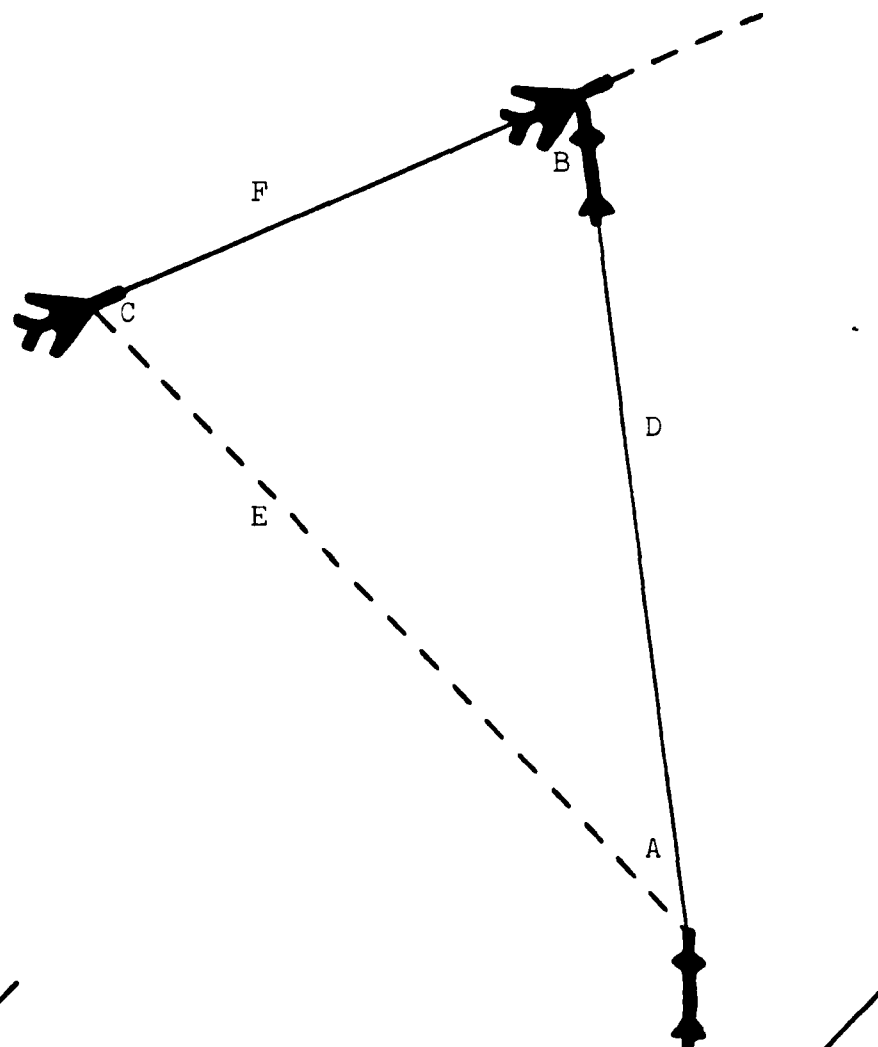


Fig. 10. Surface to Air Missile Intercept Profile

$$FTIME = [SIN(XX(51)) (XX(53))] / [SIN(B)(ATRIB(11))] \quad (28)$$

where XX(53) is the slant range.

The projected flight distance of the missile is then computed by the equation

$$ATRIB(15) = ATRIB(11) (FTIME) \quad (29)$$

and stored in attribute 15. PKILL then uses all of this information to determine the feasibility of an immediate launch. This PK must meet the minimum required value before the threat is allowed to launch the missile. If an immediate SAM launch is feasible, then PKILL schedules event 16 to occur one second later; otherwise, event 15 is rescheduled to allow the PK to increase. The final function of event 15 is to determine whether or not the aircraft will ever enter the engagement envelope of a particular threat that is committed on that aircraft. This decision is based upon the output of GEOM. If it is determined that the aircraft will not enter the envelope of a threat, then the threat is released from that aircraft. The appropriate global variable, XX(I+70) or XX(I+72), is decreased by one and event 17 is scheduled for the threat.

Event 16 is initially scheduled from subroutine PKILL when a missile launch occurs. This event simulates the intercept profile flown by the missile. As the missile is launched subroutine GEOM is called to determine the slant range to the target. Event 16 is then rescheduled at one second intervals

which causes GEOM to be called once each second. A new slant range is computed each time GEOM is called and the total distance flown by the missile is computed. This process is repeated until the difference between the slant range to the target and the total distance flown by the missile is less than or equal to the lethal radius of the missile. When this occurs, PKILL is again called to determine the success or failure of the shot. Recomputing the slant range and missile flight distance at one second intervals allows the aircraft to maneuver during missile flight. The missile then, in effect, recomputes a new intercept point each second.

Event 17 represents the expiration of the confounding delay for each threat. When the delay has elapsed, event 17 resets attribute 17 of the threat to zero. This frees the threat to begin searching for another aircraft.

Summary

The previous paragraphs have attempted to explain the interoperation of the simulation model through a step by step approach. These descriptions are designed to aid in the overall understanding of the model and how the computer program accomplishes various tasks. Only the major aspects of each subroutine and event have been outlined in this section, and the intricacies of the model can be observed only by referring to the computer listing in Appendix F.

IV Data Collection

Measure of Merit

In this thesis, each simulation run begins with a flight of two attack aircraft entering the CAS system. Each simulation run is characterized with specific values assigned to each factor level. With these conditions specified, then the target kill effectiveness of the aircraft can be measured by the total number of targets killed. However, the air defense system will also have a degree of effectiveness based upon the combination of factor levels being considered. This can be measured by the total number of aircraft shot down. Thus, the measure of merit for the model becomes the ratio of these two effectiveness measures, or more simply stated, the aircraft kill-to-loss ratio. It should be re-emphasized that this kill-to-loss ratio is to be used only as a tool for comparing the factor effects and interactions, and may not represent the actual ratios that would be encountered in a real combat situation.

Sample Size Determination

After designing and constructing the simulation model, one of the next major considerations is to determine the necessary number of replications to assure that the mean ratio computed for each factor level combination satisfies the desired accuracy requirements. A trial experiment of ten simulation runs was performed with each factor maintained

at a fixed level. The results of the experiment were as shown below:

<u>Run Number</u>	<u>Ratio</u>
1	2.5
2	0.5
3	1.0
4	1.0
5	8.0
6	0.5
7	0.0
8	1.0
9	0.0
10	0.0

The objective was to be at least 95 percent confident that the sample mean would be within one unit of the true mean. To determine the number of runs, N, required to achieve this level of accuracy, the method outlined by Shannon (Ref 22:189) was used. The required number of runs is computed using the equation

$$N = \frac{t^2 S^2}{d^2}$$

where t = tabulated t statistic,

S^2 = estimate of variance obtained in the trial experiment,
and

d = the half width of the desired confidence interval.

The necessary computations are:

$$\bar{X} = \frac{\sum X_i}{n} = \frac{(2.5 + .5 + 1 + 1 + 8 + .5 + 0 + 1 + 0 + 0)/10}{10} = 1.45$$

$$S^2 = \frac{1}{n-1} \sum (X_i - \bar{X})^2 = 5.86$$

$$t_{.05} = 1.833 \text{ for } 9 \text{ degrees of freedom}$$

$$t^2 = 3.36$$

$$d = 1.0$$

$$N = \frac{t^2 S^2}{d^2} = \frac{(3.36)(5.86)}{1.0} = 19.7$$

Based on this result, it was concluded that the simulation should be run 20 times for each factor level combination. This will insure that the sample ratios are within one unit of the true ratios.

To eliminate the possibility of auto-correlation within the output data, the model was designed in such a manner to insure independence of the output data points. Each data point represents the mean kill-to-loss ratio achieved over 20 simulation runs. Each of these runs begins with the same parameters and conditions. The random number stream runs continuously for the collection of this data point. When the next data point collection process begins, the random number stream is reinitialized and a new set of conditions is established. The same collection process is then repeated for this 20 run sequence. Thus, each data point is generated totally independent of the others.

Summary

The aircraft kill-to-loss ratio was chosen as the measure of merit for this thesis. This chapter has attempted to explain why this choice was made. The sample size determination revealed that 20 runs would be sufficient to achieve the desired accuracy in the data collection process. Finally, the subject

of auto-correlation was addressed. The model is structured in such a way to avoid time dependence between the data points.

V Verification And Validation

The evaluation of a computer simulation can be divided into three phases:

1. Verification - insuring that the model behaves as it was intended to behave.
2. Validation - testing the agreement between the behavior of the model and that of the real system.
3. Problem analysis - the drawing of statistically significant inferences from the data generated by the computer model (Ref 22:30).

The purpose of this chapter is to address the verification and validation of the model developed for this thesis. Problem analysis will be the topic of the next chapter.

Verification

Model verification was a continual process, with the model being tested for proper operation after the addition of each event and subroutine. The modular design of the model, as well as the event oriented SLAM simulation language, facilitated this systematic verification process.

During the verification phase of the computer simulation, three major aspects of the model were tested:

1. The data obtained from statistical distributions was tested for goodness-of-fit.
2. The aircraft flight profile and aircraft/threat interactions were monitored to verify proper operation of the model.

3. The model was tested at extreme values of input variables to assure that results were logical and consistent with the design of the model.

Print statements were inserted at appropriate places in the computer model to record the values of attributes and variables of interest. Also, files were printed, and the correct value and order of their contents was verified.

Distributions Goodness-of-Fit Tests. The distributions used in this simulation model were tested for goodness-of-fit by applying the Kolmogorov-Smirnov test. Sample data was obtained from trial simulation runs, and data conformity to the desired distributions was evaluated. All of the tests performed failed to reject the accuracy of the assumed distributions. The distributions were tested and the results of the tests are listed in Table VII. The Max (Abs Diff) for each distribution was obtained from SPSS. A tabulated value greater than the Max (Abs Diff) indicates that the distribution is producing the desired data.

Appendix G contains the SPSS input and output data for the SAM A/SAM B X-coordinate distribution goodness-of-fit test. This appendix also illustrates the appropriate test of hypothesis and interpretation of the Max (Abs Diff) test statistic.

Operation of Model. The proper operation of the model was verified by monitoring the aircraft flight profile and aircraft/threat interaction during all phases of the simulated CAS mission. Hand calculations were performed as

TABLE VII
DISTRIBUTION GOODNESS-OF-FIT TEST RESULTS

<u>Distribution</u>	<u>Sample Size (n)</u>	<u>Max (Abs Diff)</u>	<u>Tabulated Value ($\alpha = .05$)</u>
Aircraft heading	12	.3110	.3754
Distance to PUP	12	.3151	.3754
Target X-Coordinate	12	.2464	.3754
Target Y-Coordinate	12	.2305	.3754
SAM A / SAM B X-Coordinate	25	.1300	.2640
Threat Y-Coordinate	44	.1459	.2006
Maverick lock-on time	10	.3667	.4092
FAC briefing	8	.2650	.4543

necessary and compared to computer results, with probability of kill calculations being of particular interest.

Events 1-13 of the computer model deal with the aircraft flight profile. Included in these events are the aircraft flight path relative to the ground target, attack parameters, weapon selection and employment, probability of target kill, and post-attack options based on remaining fuel and weapons loads. These and other aspects of the aircraft flight profile were found to perform as designed.

Events 14-17 are concerned with simulating aircraft/threat interactions. The air defense search, acquisition, tracking, and firing phases are included in this section of the model.

The simulation of command and control, threat sequencing from one aircraft to another, and proper timing delays were other aspects of the model requiring verification. All phases of aircraft/threat interaction proved to operate as planned.

Numerous simulation runs were accomplished to verify the proper operation of the model. Plots of aircraft flight paths relative to threat and target locations aided the verification effort. Figure 11 illustrates two of the verified flight profiles, one resulting in a successful attack, and the other resulting in the loss of an aircraft. Appendix H contains computer output and a detailed example of the approach used to confirm the proper operation of the model.

Testing the Model at its Extremes. During this phase of the verification process, certain variables included in the model were set at levels well beyond those planned for the experiment. All such simulation runs behaved as expected.

When the aircraft ingress altitude was set at 1000 feet, an increase in aircraft kills was recorded. A simulation run made with aircraft velocity set at 100 knots resulted in a significant increase in SAM kills; however, when the aircraft velocity was set at 2000 knots, no SAM kills were recorded.

Navigation errors well in excess of those expected were also simulated. When the standard deviation of the aircraft heading distribution was set at 20 degrees and the standard deviation of the distance to PUP distribution was set at 20 percent of the computed distance, kill-to-loss ratios decreased significantly.

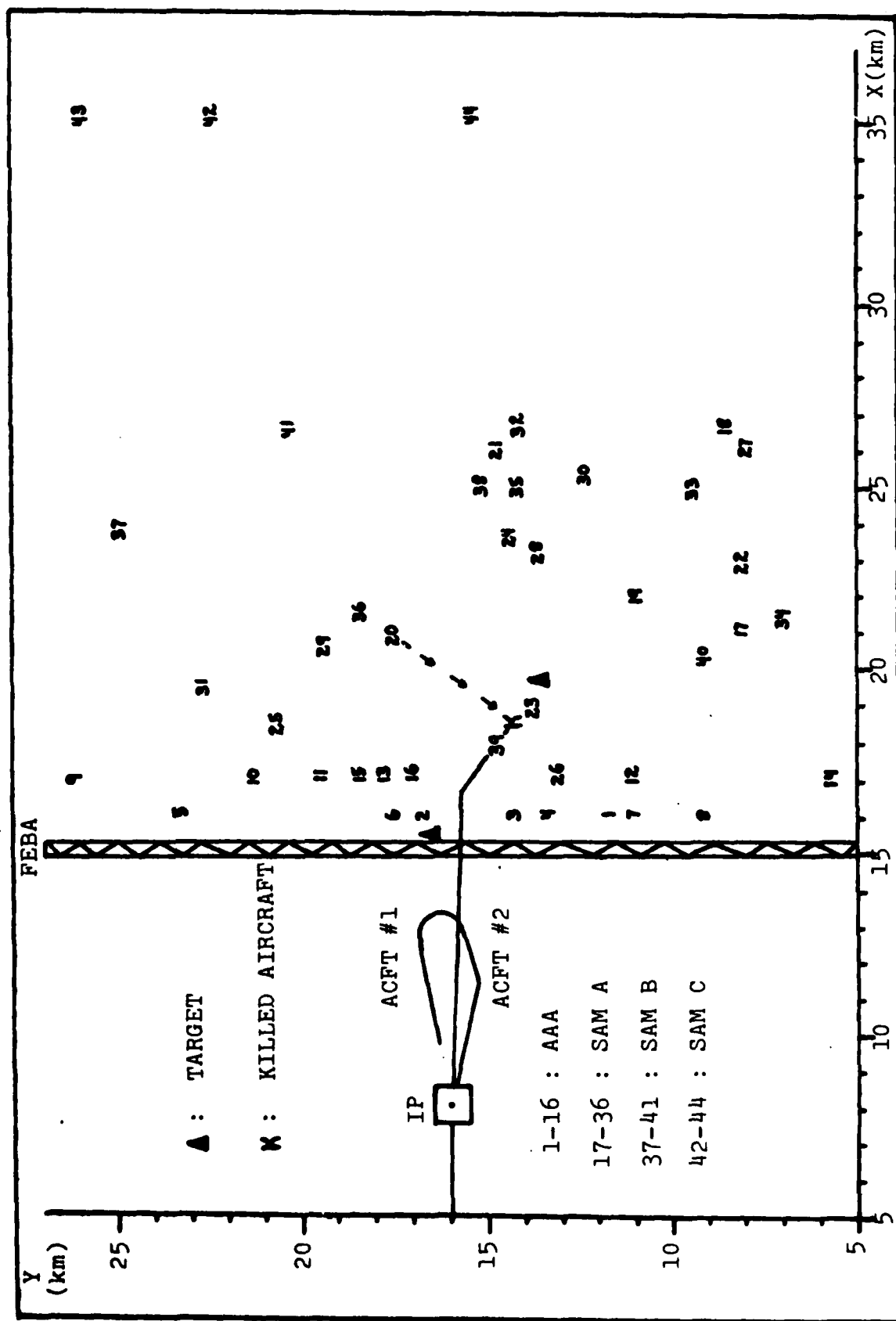


Fig. 11. Verification Diagram for Aircraft/Threat Interactions

Validation

When validating a computer simulation model it is often useful to compare simulated results with the results of a known real world system. Applying this technique to the close air support environment of Central Europe is not possible because actual data based on combat experience is not available. However, for a model of this type other methods of validation are possible.

Law and Kelton (Ref 16:338) discuss a three step approach to validation. These three steps are listed below:

1. Develop the model with high face validity.
2. Test assumptions of the model empirically.
3. Determine how representative the simulation results are.

These are the criteria used to establish the validity of this CAS simulation model.

Face Validity. A model that has high face validity is one which seems reasonable to people who are knowledgeable about the simulated system. Face validity was a driving force behind each phase of this model's development. Toward this end, individuals familiar with the CAS mission and the opposing air defense threat were consulted during the design of the model.

Experts in the CAS mission from the weapons and tactics division, 31st Tactical Fighter Wing, Homestead AFB were interviewed. Crew members and instructors who are familiar with the CAS mission were consulted. Also, the training

division at Headquarters Tactical Air Command provided valuable assistance in the development of this model (Ref 23). All of the individuals consulted confirmed the currency of the operational concepts included in this CAS simulation.

The threat array included in this model was developed in consultation with experts in the field of Soviet air defense systems. Information on Soviet attack strategy and air defense deployment was obtained from these sources (Ref 7).

Empirical Testing of Assumptions. The assumptions built into this model were included to simplify the model, while maintaining model validity. The experts consulted during model development confirmed that these assumptions were reasonable, given the limited scope of this research effort.

Simulation Output Data. A modified Turing test was used to validate the simulation output data (Ref 16:341). The object of a Turing test is to find people who are directly involved with the actual system and ask them to compare the results of the simulation with the outputs from the real system (Ref 22:29). Since there is no actual kill-to-loss ratio data for the close air support system presently found in Central Europe, the Turing test was modified for application to this model.

Four crewmembers, each with extensive CAS experience, were asked to predict the kill-to-loss ratios for CAS missions under various attack and threat scenarios. The ratios obtained from the crewmembers were then compared to the output data from the simulation model. The predictions of the mission

experts agreed favorably with the model output data.

Summary

The first two phases of the evaluation of this close air support simulation model were verification and validation. The model was verified by performing goodness-of-fit tests on statistical distributions, checking the proper operation of model activities and calculations, and evaluating the model at extreme values of input variables. Validation was accomplished by assuring the model was developed with face validity, testing all assumptions empirically, and performing a modified Turing test on simulated output data. All verification and validation results were satisfactory.

VI Data Analysis

The experimental design chosen for this thesis was a full factorial design with five factors. Four of the factors were evaluated at two levels while the fifth factor was evaluated at four levels. This design will be discussed more thoroughly in the following paragraphs. After using the model to collect the required data, an extensive analysis sequence was conducted on the data. This analysis was accomplished in various phases. The first phase was to perform two five-way analysis of variance (ANOVA) runs using the Statistical Package for the Social Sciences (SPSS). The purpose of the first five-way ANOVA was to analyze all of the effects and interactions of the factors. The second five-way ANOVA was performed with all the three-way and higher interactions suppressed. The input data and results for this phase are included in Appendix I. The next phase of analysis was two four-way ANOVA runs using only the four factors that were found to be significant. The first four-way ANOVA considered all interactions, while the second run suppressed the three-way and higher interactions. The results of this analysis are included in Appendix J. The next phase of the analysis was to perform individual one-way ANOVA runs to determine the significance of each factor separately. These results are included in Appendix K. The final phase of the data analysis was an attempt to determine the optimal attack option as a function of the factor level combinations. This

was done by performing a one-way ANOVA in conjunction with the multiple range tests to compare the kill-to-loss ratios of each combination for the various factor levels. This resulted in the comparison of 64 different attack scenarios. The results are included in Appendix L. Following the data analysis sensitivity analysis was performed on various parameters of the model. An example of the sensitivity analysis results is included in Appendix M.

Experimental Design

As stated previously, the objective of this thesis was to analyze the effects and interactions of various factors within the CAS system. Although there are many factors that influence the CAS system, this analysis is limited to five factors that were chosen because of their relatively high degree of importance. The analysis of these five factors and their interactions is considered sufficient to draw some valid inferences about the system behavior. The five factors chosen for the analysis are:

1. Aircraft airspeed.
2. Aircraft penetration distance behind the FEBA.
3. Aircraft weapons load.
4. The availability of enemy EW radars.
5. The number or density of defensive threats within the battle area.

The first factor, airspeed, is set at two levels. These levels are 385 knots and 500 knots. These particular airspeeds

were chosen to represent the combat airspeeds of the most likely aircraft to be employed in the CAS role.

Aircraft penetration distance behind the FEBA was evaluated at two levels. The first level allows the aircraft to operate up to two kilometers behind the FEBA. This represents the situation where the CAS aircraft is employed only along the leading edge of the FEBA. The second level allows aircraft penetration as far as six kilometers. This level is designed to evaluate the situation of penetrating into the defenses and its effect on the kill-to-loss ratio.

The aircraft weapons load is evaluated at two levels. Level one allows the aircraft to have the 30mm cannon as its only weapon. This represents the situation that might be encountered after the supply of Maverick missiles is depleted. The second level allows the aircraft to carry six Maverick missiles as well as the 30mm gun. This is the desired load when the weapons are available.

The EW availability is evaluated at two levels. Level one represents the situation when EW radars are available. Level two represents the situation where no EW is available.

The final factor, threat level, is evaluated at four levels. Level one represents the condition where no defense suppression has been accomplished, and therefore, all threats are at their maximum numbers. Level two represents the situation where defense suppression has been accomplished on the AAA threat. Fifty percent of the AAA units are removed from the model for this level. Level three represents

the situation where the suppression effort was directed towards the SAM A units. This effort effectively suppressed 50 percent of the SAM As. Level four directs the suppression effort towards the SAM B units, and again eliminates 50 percent of the units.

The factors and levels are summarized in Table VIII.

TABLE VIII
FACTORS AND LEVELS ANALYZED

FACTOR \ LEVEL	1	2	3	4
Airspeed	385 knots	500 knots	—	—
Penetration	2 km	6 km	—	—
Weapons	30 mm	30 mm	—	—
	0 Mav.	6 Mav.	—	—
EW	Yes	No	—	—
Threat	All threats included	50% AAA suppressed	50% SAM A suppressed	50% SAM B suppressed

A full factorial design was used for this experiment. This means that the model was run with every possible combination of the factors and levels. This allowed identification and interpretation of factor interactions. A total of

$$(2)^4 (4) = 64$$

cells were analyzed. Using twenty replications of each cell, as discussed in Sample Size Determination, a total of 1280 simulation runs was required. The factor level for the threat

is shown in Table IX for each 16 cell sequence.

TABLE IX
DESIGN MATRIX FOR THREAT LEVEL IN EACH CELL

<u>Cell</u>	<u>Threat Level</u>
1-16	1
17-32	2
33-48	3
49-64	4

The factor levels for airspeed, penetration distance, weapons load, and EW associated with each of the first 16 cells are illustrated in Table X. This exact sequence of factor levels for these four factors is repeated for each 16 cell sequence at the different threat levels.

Once the experimental design was fully specified, the experiment was conducted. The following paragraphs present the analysis of the results.

Five-Way ANOVA

Two five-way ANOVA runs were made. The first run allowed all of the factor effects and interactions to be evaluated. The second run suppressed all the three-way and higher order interactions. Both of these runs indicated that four of the five main effects (penetration distance, weapons load, EW availability, and threat density) were significant using an alpha level of .05. One main effect, aircraft airspeed, was found to be statistically insignificant. In the first ANOVA

TABLE X
FACTOR LEVEL DESIGN MATRIX FOR FIRST SIXTEEN CELLS

<u>Cell</u>	<u>Airspeed</u>	<u>Penetration Distance</u>	<u>Weapon</u>	<u>EW</u>
1	1	1	1	1
2	1	1	1	2
3	1	1	2	1
4	1	1	2	2
5	1	2	1	1
6	1	2	1	2
7	1	2	2	1
8	1	2	2	2
9	2	1	1	1
10	2	1	1	2
11	2	1	2	1
12	2	1	2	2
13	2	2	1	1
14	2	2	1	2
15	2	2	2	1
16	2	2	2	2

run seven two-way interactions, four three-way interactions, and two four-way interactions were found to be significant. The five-way interaction was also found to be significant. In the second ANOVA run, only six two-way interactions were found to be significant. When the three-way and higher order interactions were suppressed, all of the two-way interactions lost some degree of significance. One two-way interaction that was significant in the first run became insignificant in the second run. The interaction which became insignificant in the second ANOVA run was the interaction between weapons load and EW. It was only marginally significant at the .05 level in the first ANOVA run.

Main Effects. The only main effect found to be statistically insignificant was airspeed. This was true for both ANOVA runs. This result is not totally unexpected. The weapons employed by the aircraft in this model are point-to-shoot weapons, and their accuracy is relatively independent of the aircraft airspeed. In this respect, airspeed contributes very little to the number of targets killed, so long as the pilot can point his aircraft at the target and launch his weapon. It should not be concluded, however, that airspeed is totally insignificant as a factor in aircraft survivability. In fact, quite the contrary is true. Of the four remaining factors, airspeed had a significant interaction with three of them. The only factor it did not interact with was weapons load.

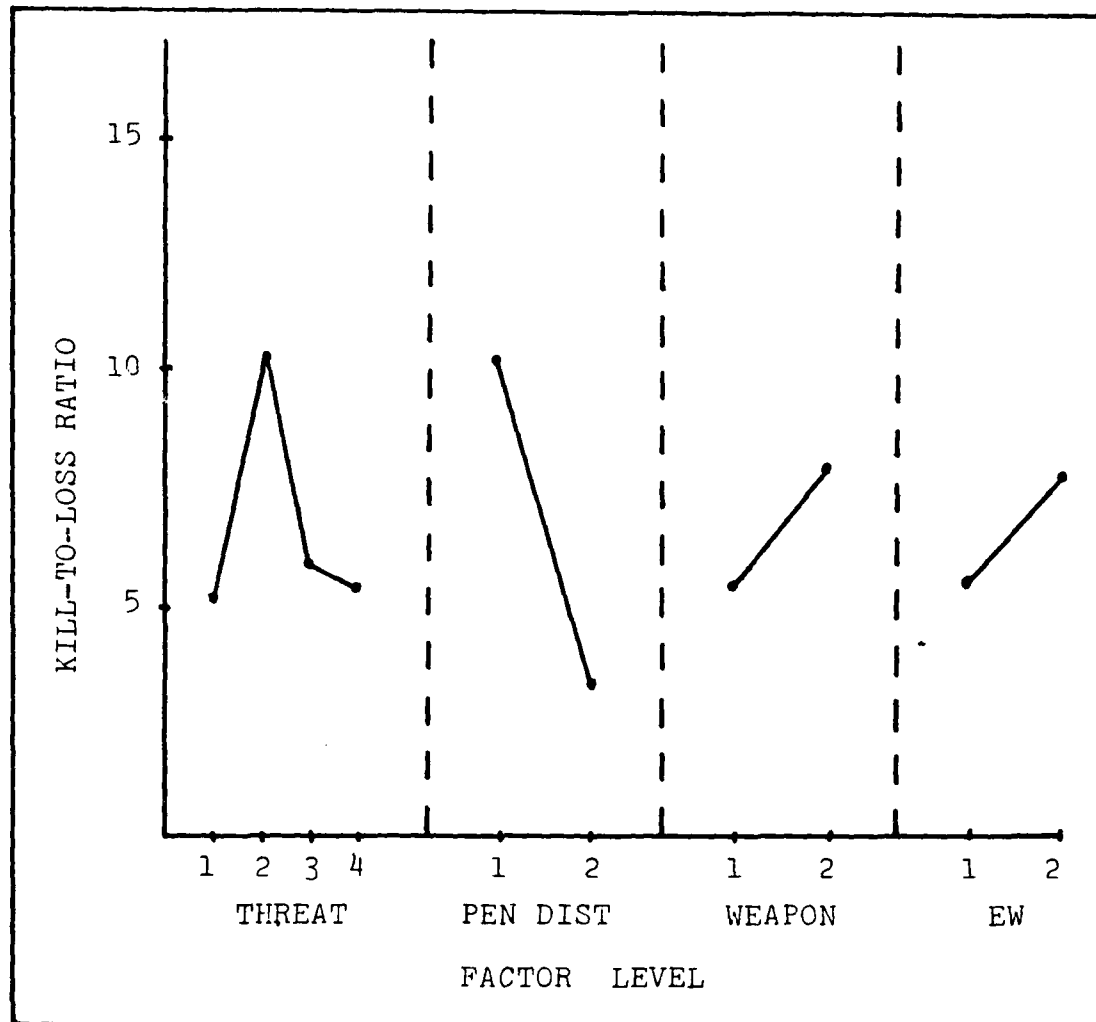


Fig. 12. Influence of Main Effects

The main effects that were found to be statistically significant are depicted graphically in Figure 12. When interpreting this figure and all subsequent graphs in this chapter, it should be remembered that only the end points of each straight line segment represent measured data points. The end points represent the kill-to-loss ratio for that particular factor level. The straight line connecting the end points has no significance other than to illustrate the

change in kill-to-loss ratio between factor levels. The fact that the lines are straight does not imply a linear relationship and no attempt has been made to evaluate these intermediate factor levels.

All of the main effects behaved as expected. When analyzing the threat level effect, the lowest kill-to-loss ratio is experienced at level one where all of the threats are included in the scenario. When the AAA is suppressed at level two, the ratio increases significantly. The kill-to-loss ratio decreases again when the AAA is put back into the model and the individual SAMs are suppressed. This indicates that the AAA systems are achieving most of the aircraft kills. A relatively high kill-to-loss ratio was achieved when the aircraft was restricted to operating within two kilometers of the FEBA. However, as the penetration distance increased to six kilometers, the ratio decreased significantly. The weapons load and EW availability also produced logical results. When Mavericks are included as part of the weapons load, the ratio increased. This can be attributed to the stand-off capability of the Maverick. Also a higher ratio was achieved when the EW radars were removed from the model. The next subsection will discuss the two-way interactions between these factors.

Two-Way Interactions. The following two-way interactions were found to be significant:

1. Threat vs. airspeed.
2. Threat vs. penetration distance.

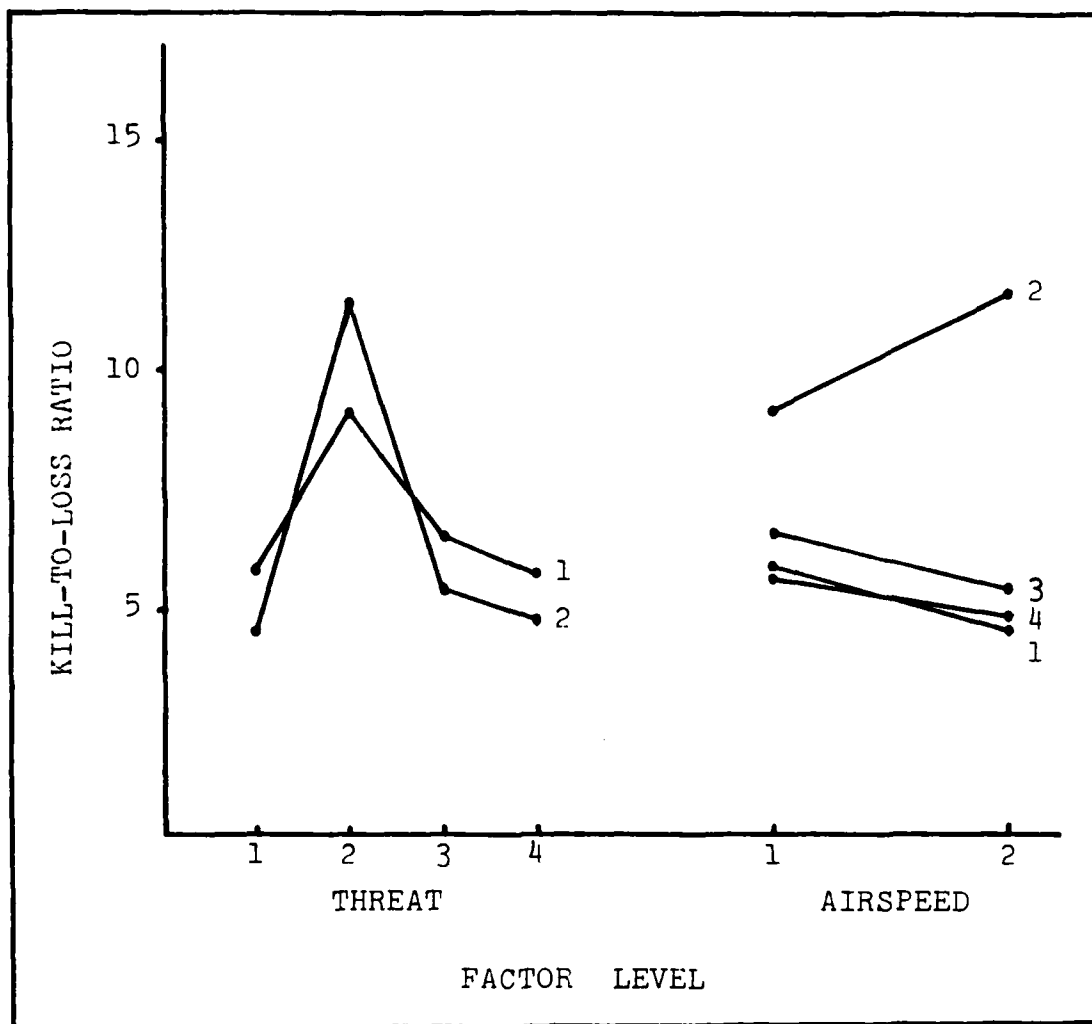


Fig. 13. Interaction Between Threat and Airspeed

3. Airspeed vs. penetration distance.
4. Airspeed vs. EW.
5. Penetration distance vs. weapon load.
6. Penetration distance vs. EW.
7. Weapon load vs. EW.

The interaction between the threat and the aircraft airspeed is shown in Figure 13. From this graph, it can be observed that the highest kill-to-loss ratio for both airspeeds is achieved at threat level two where the AAA systems are reduced.

This is in direct agreement with the main effect of the threat level which indicates that the AAA units achieve most of the aircraft kills. Also at threat level two the higher airspeed of 500 knots provides a significant increase in the kill-to-loss ratio. At the other threat level and airspeed combinations, the interaction becomes relatively insignificant. The slower airspeed of 385 knots in these situations appears to enjoy a slight advantage over the faster airspeed. This can be attributed to the fact that precise navigation and achievement of required attack parameters is more difficult at higher airspeeds. Thus a higher percentage of the attacks will be aborted due to improper attack parameters. Also, the larger turn radius of the faster aircraft will cause the flight path to enter the engagement envelope of more threats.

The interaction between the threat and the penetration distance is illustrated in Figure 14. In all cases the kill-to-loss ratio is significantly greater for the aircraft operating within two kilometers of the FEBA than for the aircraft that must penetrate up to six kilometers behind the FEBA. This is a logical consequence since an aircraft penetrating farther behind the FEBA will most likely be engaged by a greater number of threats. Again it should be noted that the highest kill-to-loss ratios are achieved when the AAA systems are suppressed, regardless of the penetration distance.

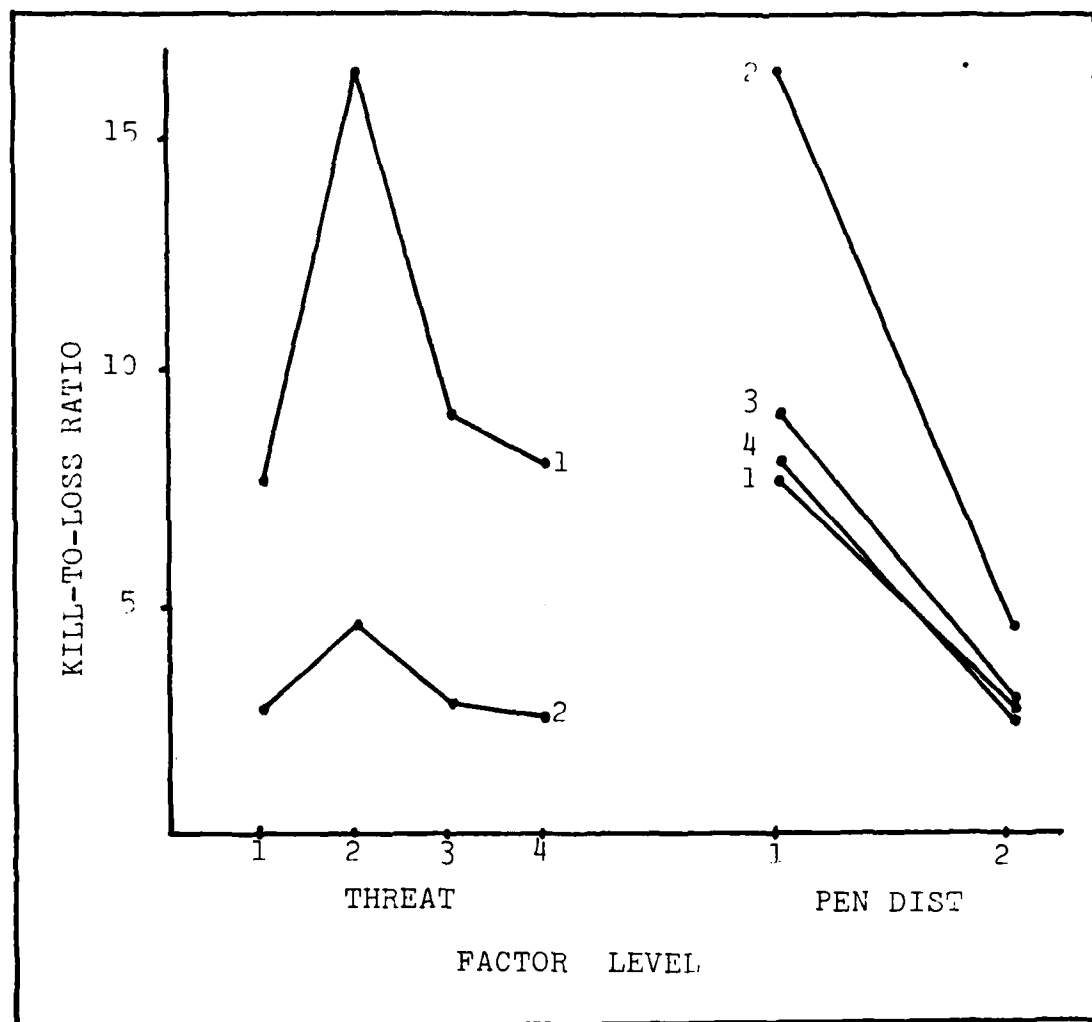


Fig. 14. Interaction Between Threat and Penetration Distance

The interaction between airspeed and penetration distance is depicted in Figure 15. The higher kill-to-loss ratios are achieved by the aircraft operating within two kilometers of the FEBA for both airspeeds. A significant decrease in this ratio is experienced for both airspeeds as the penetration distance is increased to six kilometers. While operating along the FEBA, the slower aircraft has a slightly larger kill-to-loss ratio than the faster aircraft, but as the penetration distance is increased, the faster aircraft

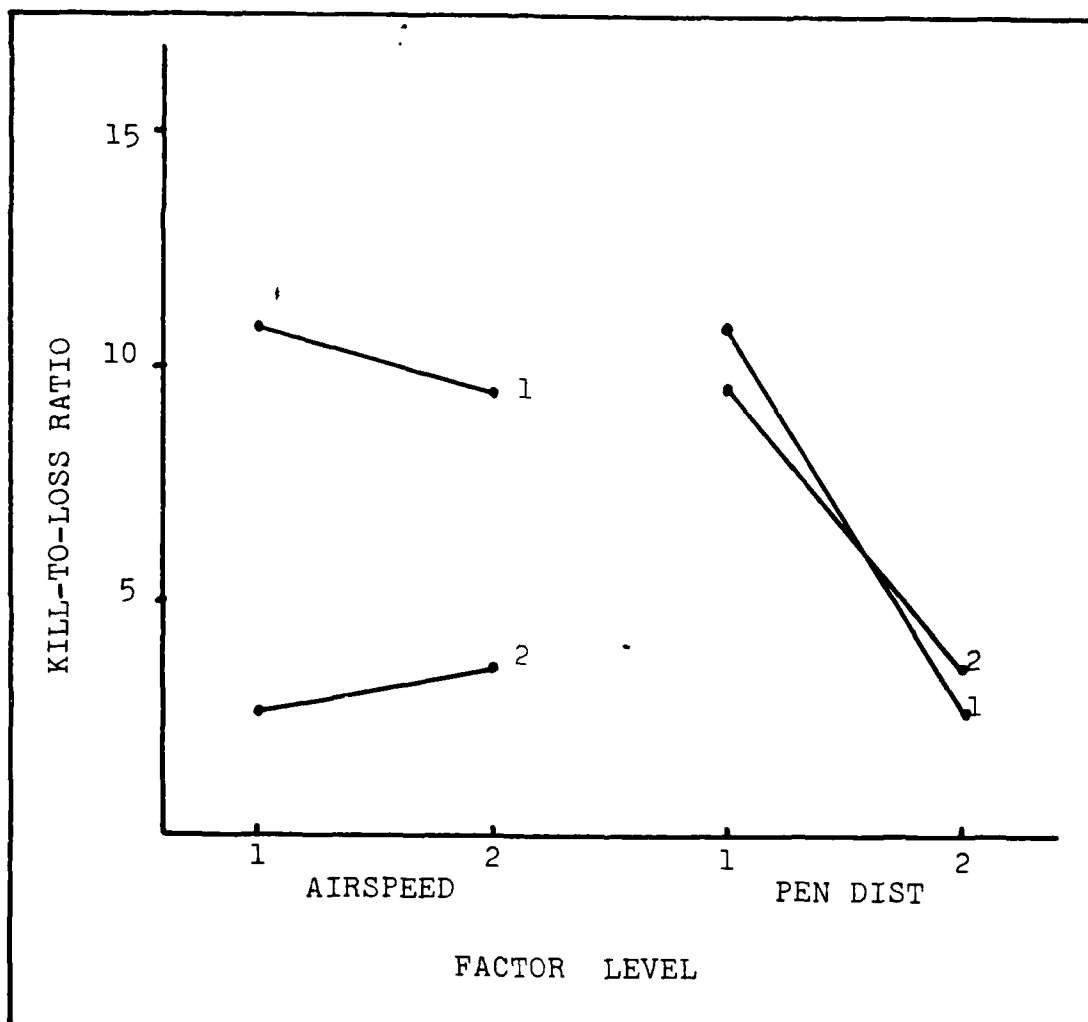


Fig. 15. Interaction Between Airspeed and Penetration Distance

achieves a higher ratio than the slower aircraft.

The interaction between airspeed and EW is shown in Figure 16. EW level one represents the situation where EW radars are available. From this figure it can be seen that a lower kill-to-loss ratio is achieved at both airspeeds when these EW radars are available. When the EW radars are removed from the scenario, the ratios increase for both airspeeds. This increase is greater for the faster airspeed than for the slower one. This can be explained by the fact

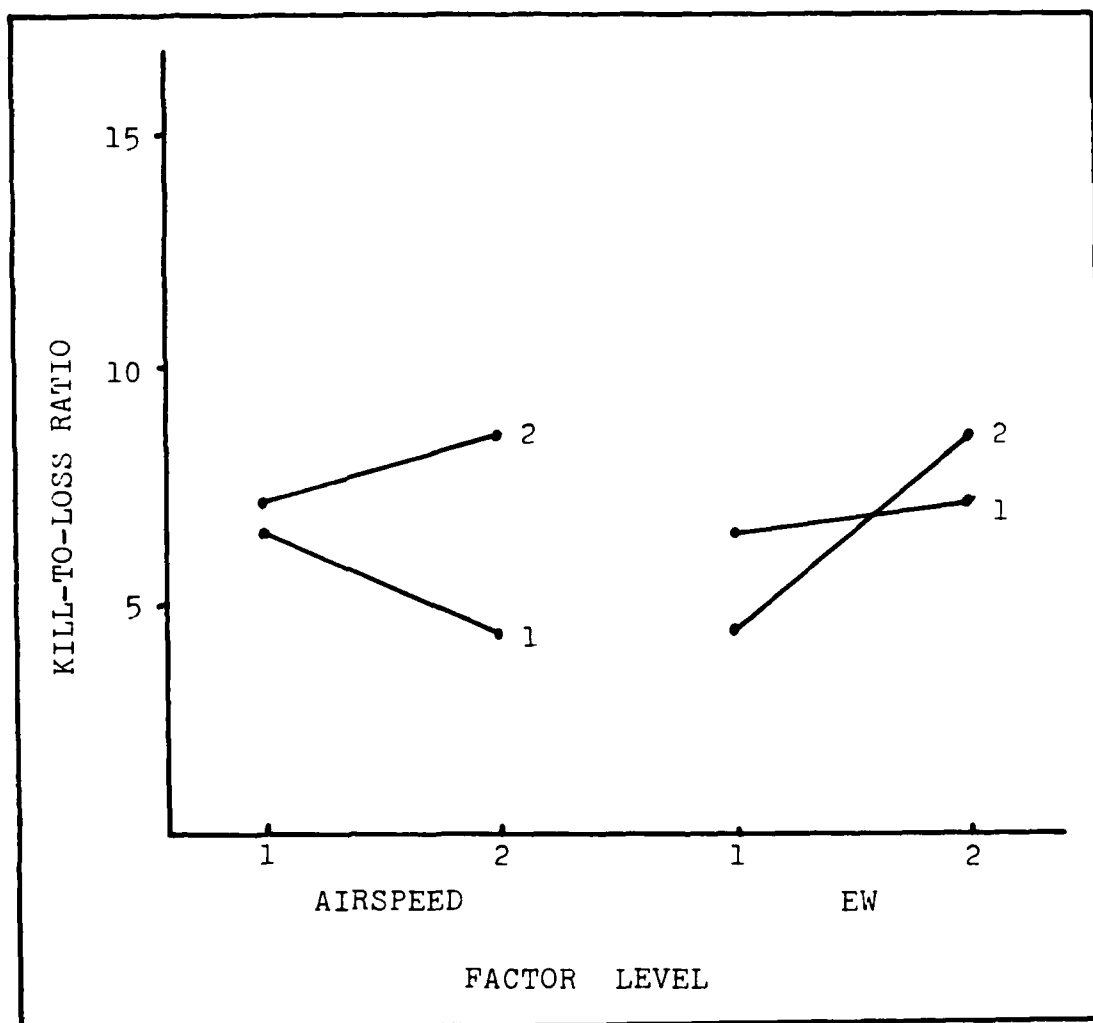


Fig. 16. Interaction Between Airspeed and EW

that a faster airplane will be further into its mission profile before being detected by the threat radars. This results in fewer threats having an opportunity to engage. Figure 16 also indicates that the faster aircraft has a lower kill-to-loss ratio than the slower aircraft when the EW radars are included. This can be explained by the fact that precise navigation and exact attack parameters are more difficult to achieve at higher airspeeds. This results in more attacks being aborted for improper attack parameters. Also, target

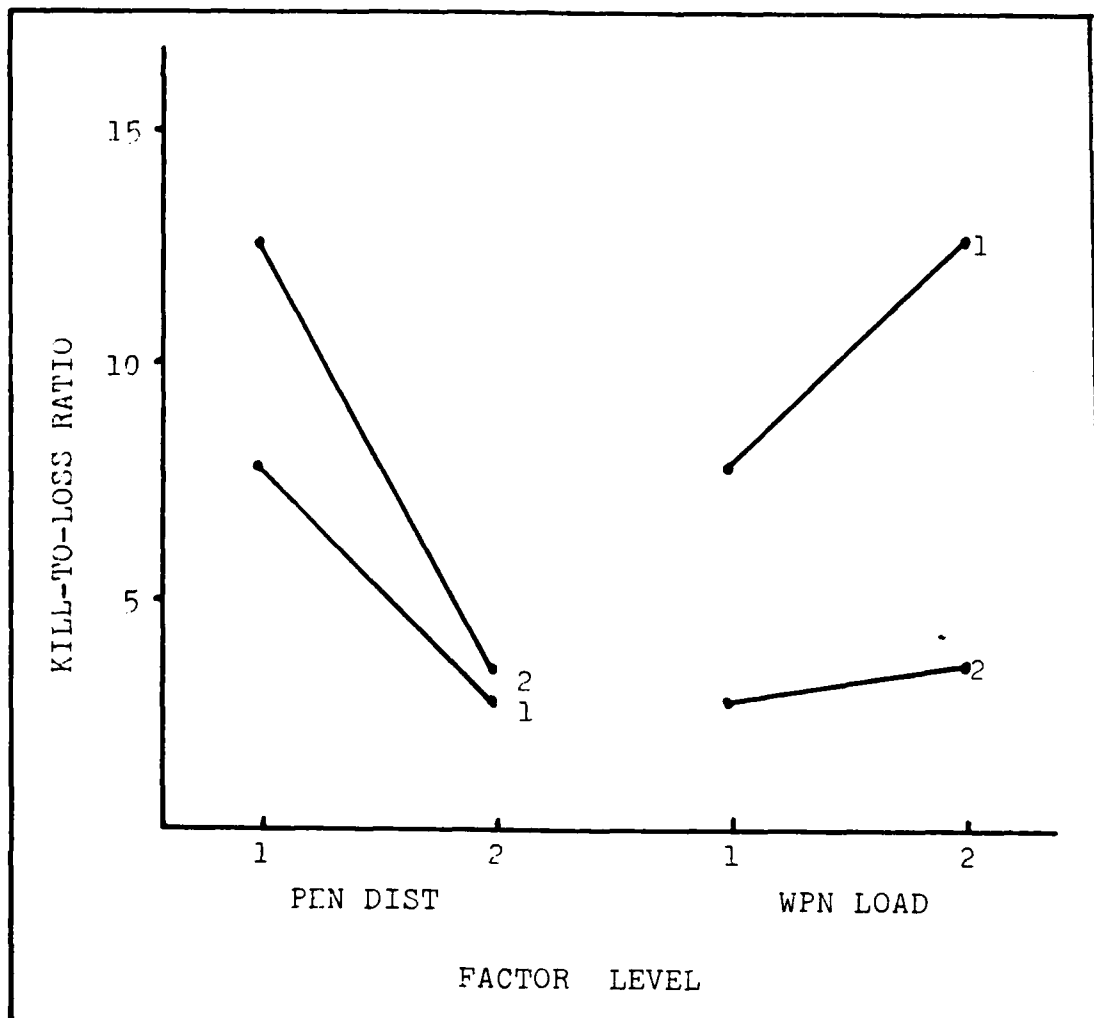


Fig. 17. Interaction Between Penetration Distance and Weapon Load

acquisition becomes more difficult as airspeed increases.

The interaction between penetration distance and weapons load is shown in Figure 17. The highest kill-to-loss ratios are achieved while operating at penetration distance level one, which is within two kilometers of the FEBA. This is true for both weapons load combinations. As the aircraft penetrates to six kilometers behind the FEBA, these ratios decrease dramatically. Again, this is true for both weapons loads. As was expected, the aircraft with Mavericks and the

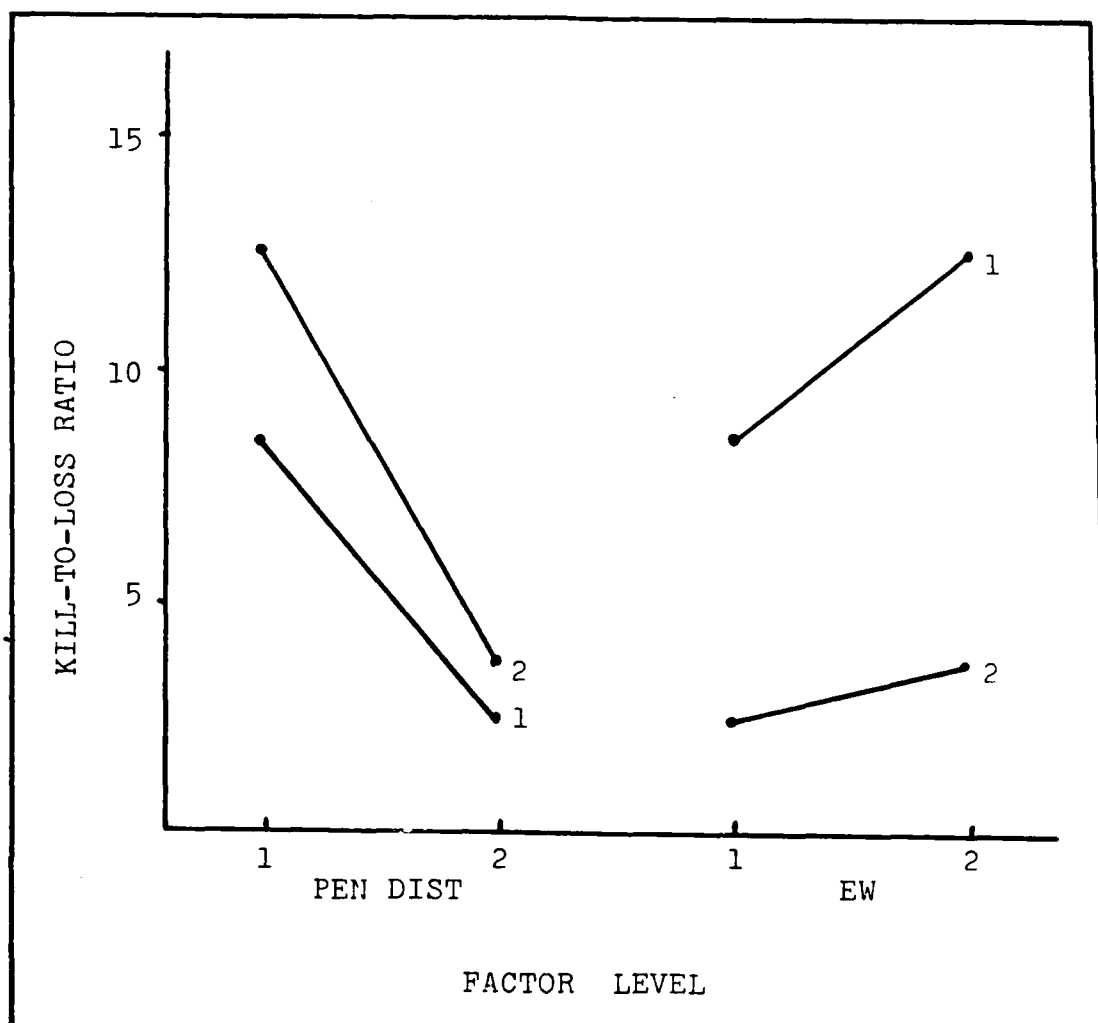


Fig. 18. Interaction Between Penetration Distance and EW

30mm gun achieves a higher kill-to-loss ratio at both penetration distances. This can be attributed to the increased stand-off range of the Maverick.

The interaction between penetration distance and EW is shown in Figure 18. Once again the dramatic effect of penetration distance is vividly illustrated. Regardless of whether the EW radars are available or not, the kill-to-loss ratio decreases significantly as the penetration distance increases. However, it is apparent that the kill-to-loss

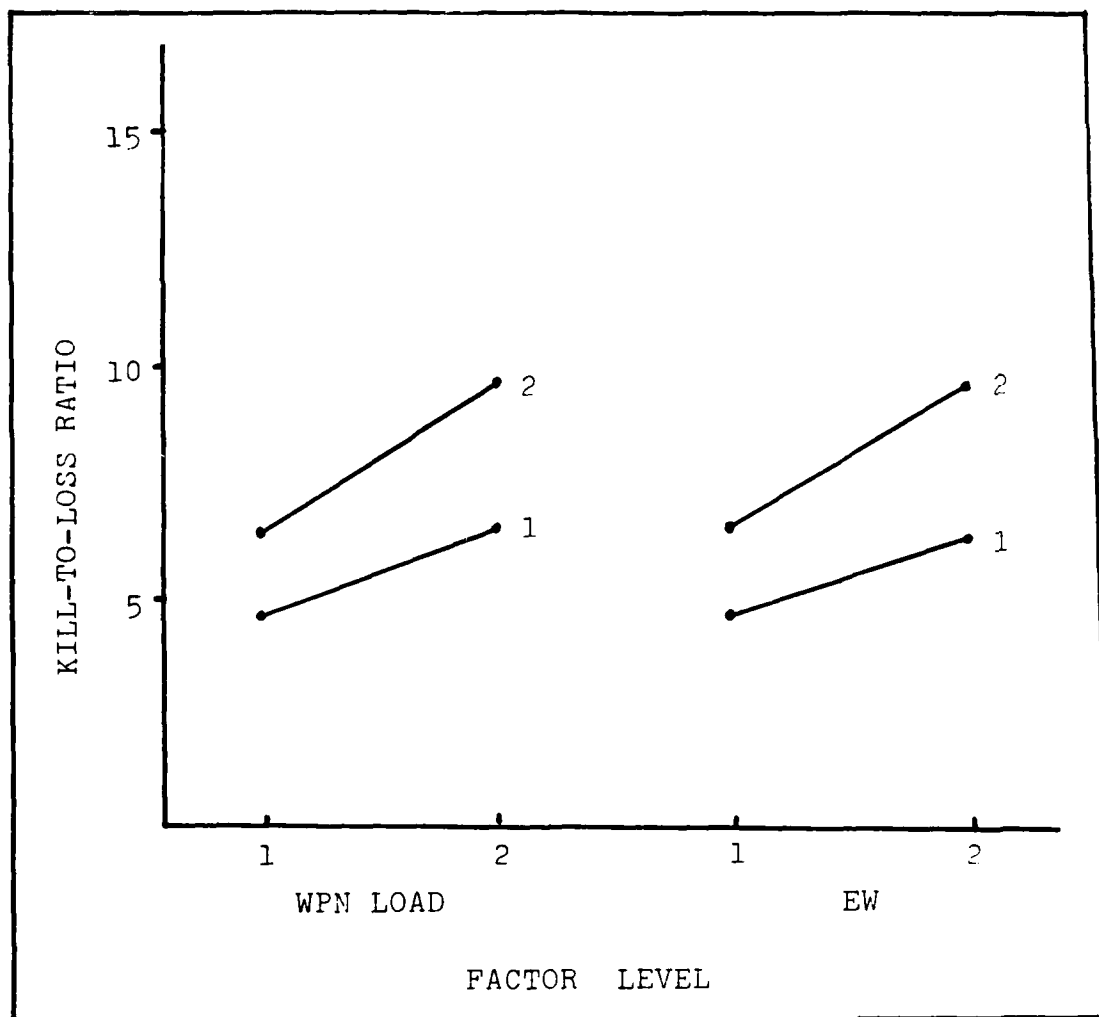


Fig. 19. Interaction Between Weapon Load and EW

ratios are significantly higher for both penetration distances when the EW radars are removed from the scenario. These results are completely logical since the absence of EW radars would delay the acquisition of the aircraft by the threats.

The interaction between weapons load and EW is depicted in Figure 19. This is not a particularly strong interaction at the .05 level. In fact, when the higher order interactions were suppressed, this interaction became insignificant. However, it can be seen that a higher kill-to-loss ratio is achieved

for both weapons loads when the EW radars are removed. As the EW radars are removed, the kill-to-loss ratio for the aircraft carrying Mavericks increases faster than the ratio for the aircraft with no Mavericks. Once again, this is because of the stand-off range of the Maverick.

Four-Way ANOVA

Since airspeed was found to be statistically insignificant in the five-way ANOVA runs, this factor was excluded for the next phase of data analysis. Two four-way ANOVA runs were made considering all the factors except airspeed. The first four-way ANOVA run included all interactions. The results of this run indicated that all of the main effects were still very significant for an alpha level of .05. It was also found that three two-way interactions were significant at this level. There were no significant interactions of an order higher than two-way. This result implies that all of the three-way and higher order interactions found in the five-way ANOVA runs were a direct result of the interplay that airspeed contributes to the model. So, even though airspeed was not a significant main effect, it is still a very important factor in the model. Although there were no significant three-way or four-way interactions found in the first ANOVA run, a second run was made with these higher order interactions suppressed. This was done to maintain consistency with the data analysis method used for the five-way ANOVA runs. As was expected, none of the results changed for this

run.

The two-way interactions that were found to be significant in the four-way ANOVA runs were:

1. Threat vs. penetration distance.
2. Penetration distance vs. weapons load.
3. Penetration distance vs. EW.

These are three of the same two-way interactions found to be significant in the five-way ANOVA, and the results were identical. Additionally, the results for the main effects in the four-way ANOVA were identical to the main effects in the five-way ANOVA.

One-way ANOVA for Each Factor

The next phase of the data analysis was to take a closer look at the main effects of each factor at its various levels. The objective was to determine which factor level, if any, resulted in the highest kill-to-loss ratio when each factor was considered separately. This was accomplished by performing a one-way ANOVA in conjunction with the Scheffe multiply range test for each factor versus kill-to-loss ratio. These tests were performed for an alpha level of .05. The results for the airspeed test indicated no significant difference in the kill-to-loss ratios achieved at the two factor levels. Each of the other four factors did have a factor level at which the kill-to-loss ratio was significantly higher.

The first factor to be tested against the kill-to-loss ratio was the threat. The one-way ANOVA indicated that a

significant difference existed between the threat levels. When the Scheffe test was performed, threat level two was found to produce a significantly higher kill-to-loss ratio than the other levels. Threat level two is the situation where 50 percent of the AAA units are suppressed. There were no significant differences between the other three threat levels. These results agree with previous data analysis, and indicate that the AAA is the most lethal threat for this scenario.

Airspeed was the next factor to be tested against the kill-to-loss ratio. The one-way ANOVA computed an F-ratio of .407, which indicates no significant difference between the factor levels. The Scheffe test reinforced this conclusion when it was unable to detect any statistical difference between the levels. This result was expected since airspeed had no significant main effect contribution in the five-way ANOVA runs.

When penetration distance was tested against the kill-to-loss ratio, an F-ratio of 249.97 was computed. This indicates a very significant difference between the factor levels. The Scheffe test indicated that penetration distance level one, operations within two kilometers of the FEBA, had a significantly higher kill-to-loss ratio than level two. This agrees with the results of previous phases of the data analysis, and indicates that the depth of penetration behind the FEBA will definitely affect the kill-to-loss ratio achieved by the aircraft.

The next factor tested was the weapons load. Factor level one represents a weapons load of 30mm only, while factor level two represents Mavericks and the 30mm cannon. The one-way ANOVA computed an F-ratio of 29.6 which indicates a significant difference between the factor levels. The Scheffe test indicates that level two will produce a higher kill-to-loss ratio than level one. This result reinforces earlier analysis and can be attributed to the stand-off range of the Maverick missile.

. The final factor to be tested was EW. Factor level one represents EW radars available and level two represents no EW radars available. The computed F-ratio was 26.01 and indicates a significant difference. The Scheffe test indicates that level two will produce higher kill-to-loss ratios than level one. This result agrees with earlier analysis and illustrates the effect of EW radars on the success of the CAS mission.

Table XI is a summary of the results of this portion of the data analysis. The optimum factor level for this table is defined as the factor level at which a significantly higher kill-to-loss ratio will be achieved. When analyzing this table, it should be kept in mind that the optimum factor level is for the main factor effects only, and does not consider the various interactions.

TABLE XI

RESULTS OF ONE-WAY ANALYSIS OF VARIANCE

<u>Factor</u>	<u>Optimum Factor Level</u>	<u>Kill-to-Loss Ratio</u>
Threat	Suppress AAA	10.3
Airspeed	_____	_____
Penetration	Two kilometers	10.2
Weapons	Mav and 30mm	7.9
EW	Not available	7.9

One-Way ANOVA of Policies

The final phase of the data analysis was an attempt to identify the optimal combinations of factor levels under which to perform the close air support mission. The objective was to try to determine the most effective way to employ the CAS aircraft for a given set of conditions. With this in mind, each of the 64 factor level combinations was designated as a separate attack policy. Each of these 64 policies is directly related to the 64 cells in the five-way ANOVA. For example, policy one is the factor level combination tested in cell one. A one-way ANOVA of kill-to-loss ratio vs. policy was run for these 64 policies. The F-ratio between groups was 14.4 which indicates that a significant difference does exist between some of the policies. The Tukey and Scheffe multiple range comparison tests were then conducted at the .05 level to determine which policies offered the higher kill-to-loss ratios. Since the Tukey method is less conservative

than the Scheffe method, it was more able to distinguish between the policies. The Tukey method identified one policy, policy 28, as having a significantly higher kill-to-loss ratio than all the other policies. The next subset contained three policies that were significantly better than the others. These were policies 19, 26, and 36. The other subsets below these contained numerous policies and will not be discussed.

Policy 28 achieved a kill-to-loss ratio of 33.4, which is significantly higher than any other ratio. This result suggests that the most effective employment of the CAS aircraft in this model is to suppress the AAA threats, maintain 500 knots airspeed, attack targets within two kilometers of the FEBA, carry a weapons load consisting of Mavericks and 30mm, and eliminate the EW radars. These results are both logical and consistent with earlier analysis.

Policy 19 achieved a kill-to-loss ratio of 24.3. This policy represents the situation where the AAA units are suppressed, 385 knots airspeed is maintained, the attack is performed within two kilometers of the FEBA, Mavericks are employed, and the EW radars are available. This policy differs from policy 28 only in airspeed and availability of EW radars. It can be seen that flying the slower airspeed and including EW radars has decreased the kill-to-loss ratio by 27 percent. However, a kill-to-loss ratio of 24.3 is still relatively high for this model.

Policy 26 achieved a kill-to-loss ratio of 19.8. This policy is not statistically different from policy 19. This

represents the situation where the AAA threats are suppressed, 500 knots is maintained, the attack is made within two kilometers of the FEBA, the 30mm gun is the only weapon available, and no EW radars are available. This policy differs from policy 28 only in the weapons load. It suggests that if the gun is the only weapon available, the aircraft should fly fast and stay close to the FEBA. Also the AAAs should be suppressed and the EW radars eliminated.

Policy 36 achieved a kill-to-loss ratio of 17. This policy is statistically the same as policies 19 and 26. It represents the situation where the SAM A threats are suppressed, 385 knots is maintained, the attack is performed within two kilometers of the FEBA, Mavericks are employed, and the EW radars are eliminated.

Table XII summarizes the analysis of these four policies. It is interesting to compare the entries in this table for policies 19 and 36. These two policies represent an aircraft that has a combat airspeed of 385 knots, a weapons load of Mavericks and 30mm, and operating within two kilometers of the FEBA. The comparison suggests that if EW radars are available, then the AAA threats should be suppressed. If EW radars are not available, then the SAM A threats should be suppressed.

Sensitivity Analysis

Several assumptions that were made for this model require a more in-depth analysis to determine the model's sensitivity to variations in the value of these assumptions. The

TABLE XII
SUMMARY OF ONE-WAY ANOVA OF POLICIES

<u>Policy</u>	<u>Threat</u>	<u>Airspeed</u>	<u>Penetration</u>	<u>Weapons</u>	<u>LW</u>	<u>Kill-to-loss Ratio</u>
28	Suppress AAA	500 knots	2 km	Mav + Gun	No	33.4
19	Suppress AAA	385 knots	2 km	Mav + Gun	Yes	24.3
26	Suppress AAA	500 knots	2 km	Gun	No	19.8
36	Suppress SAM A	385 knots	2 km	Mav + Gun	No	17.0

assumptions that were analyzed more closely are:

1. The PK required by a threat before it can launch its weapon.
2. The command and control which restricts the number of each type threat that can simultaneously engage an aircraft.
3. The Y-coordinate distribution of the threats and targets.
4. The navigation error of the attacking aircraft.

The model's sensitivity was tested for a 20 percent increase and a 20 percent decrease in each of these parameters.

The model requires an engaging threat to achieve a pre-determined PK value before it can launch its weapon. If the aircraft is in the ingress or egress portion of its profile, then the engaging threat must have a PK of .5 prior to launch. If the aircraft is maneuvering to deliver weapons, then the required threat PK is .1. This allows the threat to engage sooner in order to prevent the aircraft from delivering weapons. A simulation run was made with these PK values reduced to .4 and .08 respectively. Another run was made with the PK values increased to .6 and .12. A one-way ANOVA was performed to compare the results of these two runs with the results of the model in its base form. The F-ratio computed in the ANOVA was 1.65, which indicates no significant difference in the kill-to-loss ratios achieved. The Tukey multiple comparison test indicated the same conclusion when

it was unable to distinguish between the three runs at the .05 level. The conclusion is that the model is insensitive to a 20 percent variation in the required PK level.

The model, in its basic form, has a command and control structure that restricts the number of threats that can simultaneously engage an aircraft to 30 percent of the AAA units and 30 percent of the SAMs. A simulation run was made with this percentage reduced to 24 percent and another run was made with the percentage increased to 36 percent. A one-way ANOVA was then performed to compare the results of these three command and control structures. An F-ratio of .746 was computed, which indicates no significant difference between the kill-to-loss ratios achieved. The Tukey test validated this result. The conclusion is that the model is insensitive to a 20 percent change in the value of this parameter.

The model selects the Y-coordinate for the threats and targets from a normal distribution that is centered around the main axis of attack. The mean of this distribution is 16 kilometers, representing the main axis of attack, and the standard deviation is 5000 meters. A simulation run was made with this standard deviation reduced to 4000 meters and another run was made with a standard deviation of 6000 meters. A one-way ANOVA was then performed to compare the results of these three normal distributions. An F-ratio of 2.99 was computed, which indicates no significant difference between the kill-to-loss ratios achieved. The Tukey test echoed the

same results. The conclusion is that the model is insensitive to a 20 percent change in this normal distribution.

The navigation error experienced by the aircraft in its ingress and attack profiles is represented by two normal distributions. The heading error is normally distributed with a mean equal to the computed heading with a standard deviation of one degree. The distance error is normally distributed with a mean equal to the computed flying distance to the PUP with a standard deviation of five percent of the computed distance. A simulation run was made with the standard deviation of the heading distribution reduced to .8 degrees and the standard deviation of the distance distribution decreased to four percent. Another run was made with these standard deviations increased respectively to 1.2 degrees and six percent. A one-way ANOVA was then performed to compare these three situations. An F-ratio of 1.64 was computed, which indicates no significant difference between the kill-to-loss ratios achieved. The Tukey test indicates the same results. The conclusion is that the model is insensitive to a 20 percent change in the navigation error.

Summary

This chapter has attempted to explain the experimental design used in the model and to explain the results obtained from the data analysis. The results from the data analysis can be used as an aid in determining the optimal employment options of the CAS aircraft under a given set of conditions.

The mean square error (MSE) of the five-way and four-way ANOVA's were compared to determine the best statistical model for this scenario. The lowest MSE was obtained in the five-way ANOVA with all interactions present. This model however, is extremely difficult to accurately analyze because of the effect of the higher order interactions present. Therefore, it is not considered to be the best statistical model for the analysis of this scenario. Of the three remaining statistical models, the five-way ANOVA with the three-way and higher order interactions suppressed produced the lowest MSE. The simplicity of direct interpretation of the results of this model make it the best statistical model for the purpose of this research.

VII Conclusions and Recommendations

The objective of this thesis, as stated in Chapter I, was to analyze the effects and interactions of some of the factors that influence the effectiveness of the CAS mission. The analysis focused on how these factors contributed to the kill-to-loss ratios achieved by the CAS aircraft.

Conclusions

The conclusions are as follows:

1. The factors studied in this thesis interact heavily with one another, and the kill-to-loss ratio is very dependent upon the combination of factor levels.
2. Airspeed, by itself, does not significantly affect the kill-to-loss ratio. However, its interaction with other factors is significant.
3. For the scenario studied in this thesis, the AAA system is the most lethal threat.
4. Suppression of the AAA results in a significant increase in the aircraft kill-to-loss ratio.
5. The SAM A and SAM B units are also significant threats in this scenario.
6. The SAM C has virtually no capability against the aircraft in this scenario. This is because of its minimum altitude engagement parameter.
7. The inclusion of the EW radars in the CAS environment significantly reduces the kill-to-loss ratio. Therefore,

suppression or elimination of this element should be considered when performing the mission.

8. The stand-off capability of the Maverick missile contributes significantly to increasing the kill-to-loss ratio. Therefore, the Maverick should be included as part of the weapons load whenever possible.
9. When the penetration distance behind the FEBA is increased from two kilometers to six kilometers, the kill-to-loss ratio is dramatically reduced. Thus, if the tactical situation permits, the CAS aircraft should be employed as close to the FEBA as possible.
10. The most effective employment of the CAS aircraft in this scenario is to suppress the AAA threat, fly 500 knots, stay within two kilometers of the FEBA, carry a weapons load of Mavericks and 30mm, and eliminate the EW radars.

Although the conclusions from this model do not represent any startling new revelations, they do tend to reinforce the need to consider these factors when planning CAS operations. The fact that the results of this model agree with established tactical considerations reinforces the validity of the model. Thus, it can be concluded that this model is a valid instrument for conducting further analysis of the CAS environment. Some of the recommended areas of further analysis will be discussed later.

Recommendations

Based on the above conclusions, the following recommendations are made:

1. An adequate supply of Maverick missiles should be maintained to insure that each CAS mission has the option of employing this weapon. Research and development for improving the all weather capability of this missile should be continued.
2. When conducting CAS operations, threat suppression tactics should be employed, whenever possible, emphasizing a coordinated combined arms effort between the Army and Air Force.
3. Tactics should be employed to eliminate the enemy EW radars either through ECM efforts or interdiction of EW sites.
4. Tactics and ECM capabilities should be developed to allow more effective penetration behind the FEBA.

Recommended Areas for Follow-on Study

Like most research efforts, this thesis was unable to address all of the factors and considerations of the CAS system. The basic framework of the model developed in this thesis can be easily adapted to analyze a variety of problems associated with the CAS mission. Some suggestions are listed below:

1. This model did not consider the infrared (IR) SAM systems that would be encountered in Central Europe. Inclusion of these threats into the model would provide a more realistic view of the system.

2. A specific section of terrain in Central Europe could be modeled in more detail to analyze CAS effectiveness in that particular area.
3. SAM and AAA sites could be given multiple shots at an aircraft if the engagement situation allows.
4. Different weapons loads other than Mavericks and the 30mm cannon could be analyzed.
5. The threat scenario could be modified to study different threat concentrations and positioning.
6. The ingress and egress altitude for this model was maintained at 100 feet. This parameter could be varied to analyze its effect on the kill-to-loss ratio.
7. The weather could be modeled in more detail to determine the effect of more adverse weather conditions.
8. A more specific communications, command, and control structure for the enemy forces could be modeled.

Undoubtedly, many more details could be added to the model, but those listed above are some of the major areas that could be studied more thoroughly. Whether or not the inclusion of these factors into the model would significantly improve the validity of the output can not be answered at this time. This can only be determined by actually adding the factors and analyzing the results. The model in its present form, however, accomplishes the purpose for which it was designed and provides some insight into the CAS system.

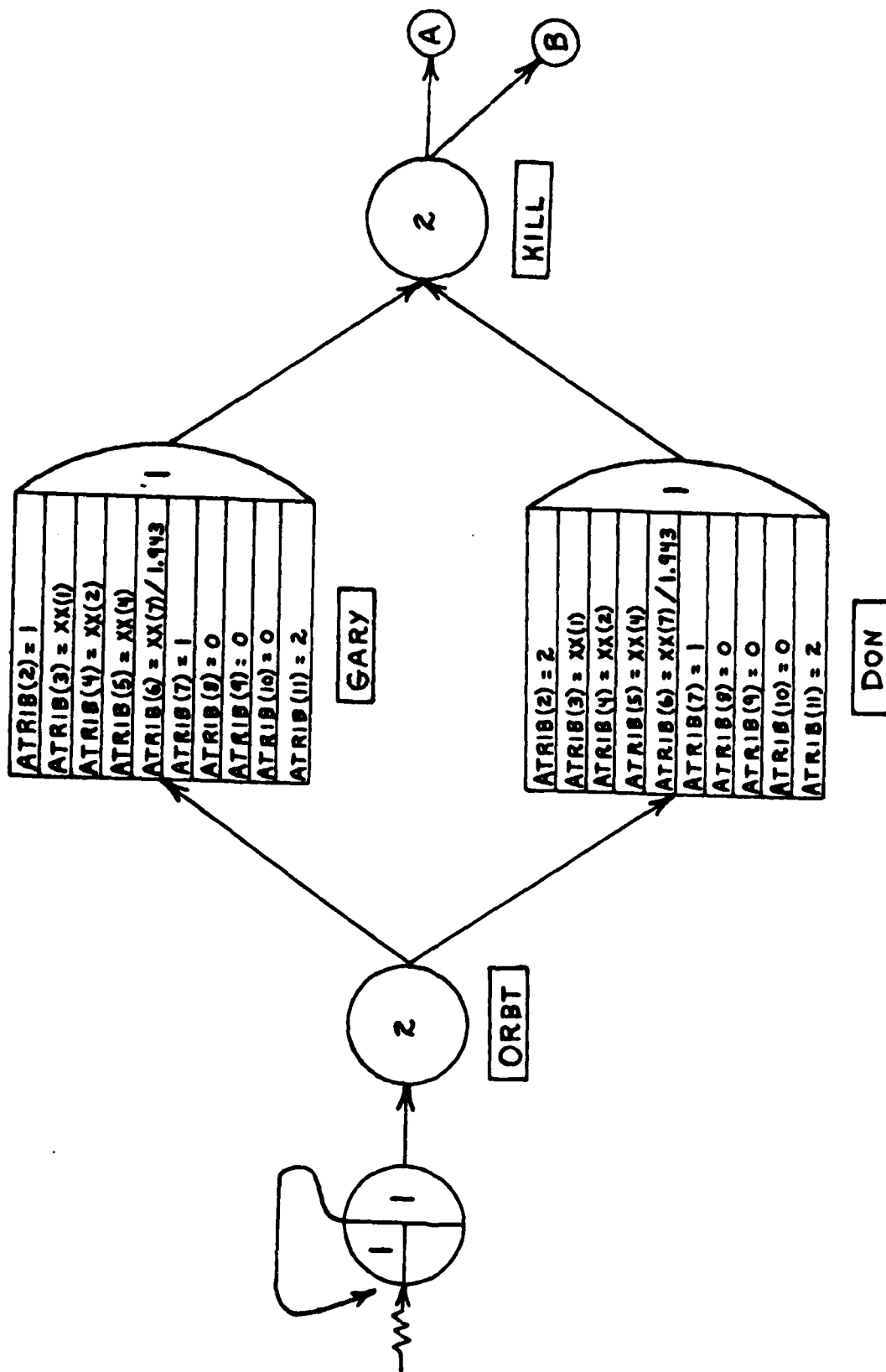
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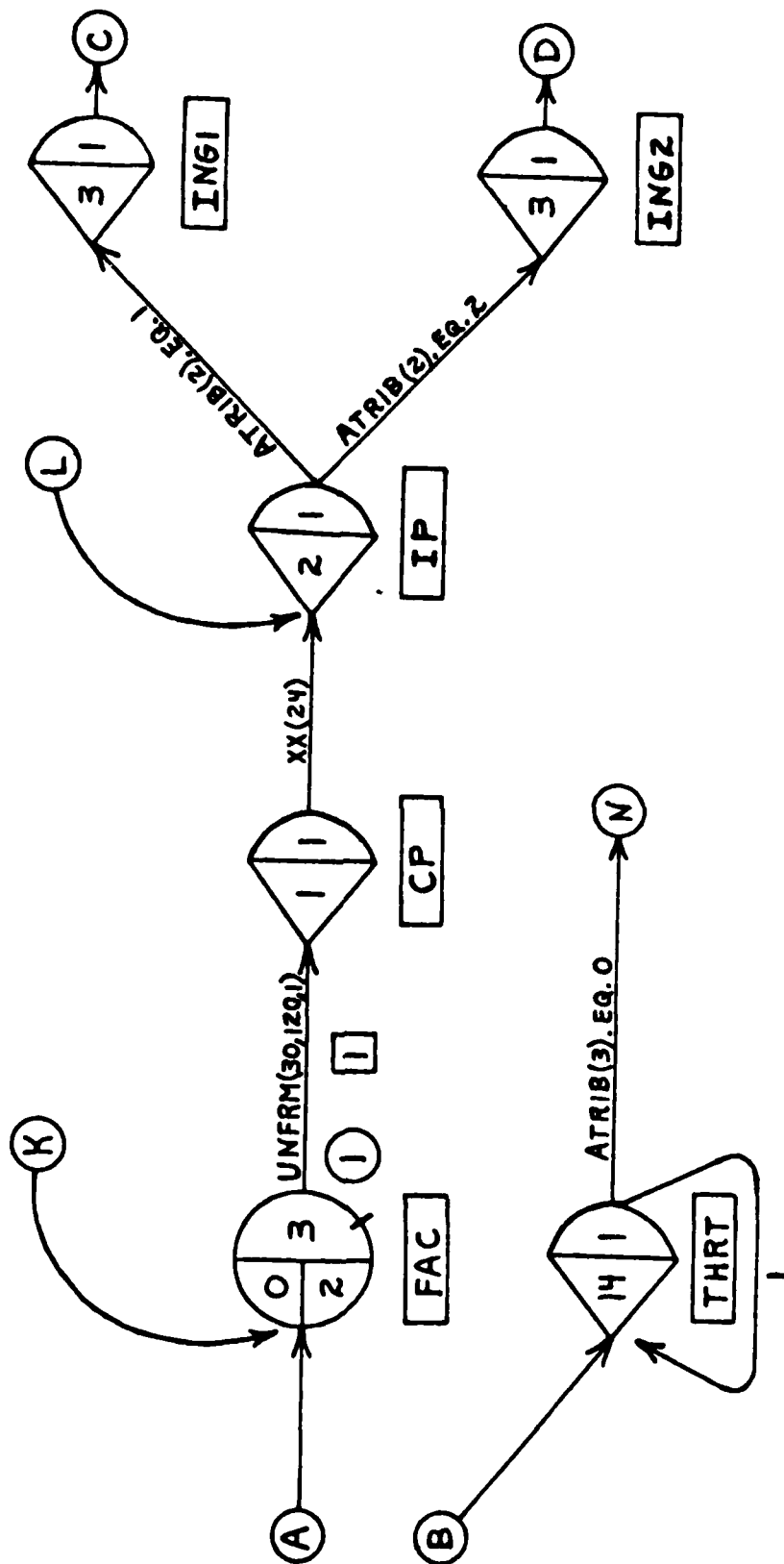
1. AFM 1-1. Functions and Basic Doctrine of the United States Air Force. Washington: Department of the Air Force, February 1979.
2. Anderson, Kenneth C. and Ronald B. Nenner. "A Wild Weasel Penetration Model." Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, March 1982.
3. Breuer, Walter. Lecture material for SE 5.81, Survivability and Vulnerability of Systems (Conventional). School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio 1982.
4. Bunyard, Brig Gen Jerry Max. "Tomorrow's War Today," Air Force Magazine, 63 (10): 64-67 (October 1980).
5. C15900.MAV.4378KFS. AGM-65 Maverick Launch Summary. Tucson, Arizona: Hughes Field Support Engineering Section, July 1982.
6. Cox, Travis. Eglin Gun Branch (telephone conversation). Eglin AFB, Florida, 12 October 1982.
7. Ferguson, Chris S. and Don McKee. Integrated Threat Division (personal interview). Wright-Patterson AFB, Ohio, 11 October 1982.
8. FM 100-5. Operations. Washington: Department of the Army, July 1976.
9. Fraser, Major Harry L. "Integration of Close Air Support and Army Aviation on the 1980's Battlefield." Research Study. Air University, Maxwell AFB, Alabama, April 1978.
10. Golden, Major August. Lecture material for EE 5.73, Electronic Warfare. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, June 1982.
11. Greene, Terrell E. "Tacair in the Defense of NATO," Astronautics and Aeronautics, 15 (3): 18-27 (March 1977).
12. Groves, Anthony. Analyst, United States Air Force Studies and Analysis (telephone conversation). Washington, D.C., 18 October 1982.

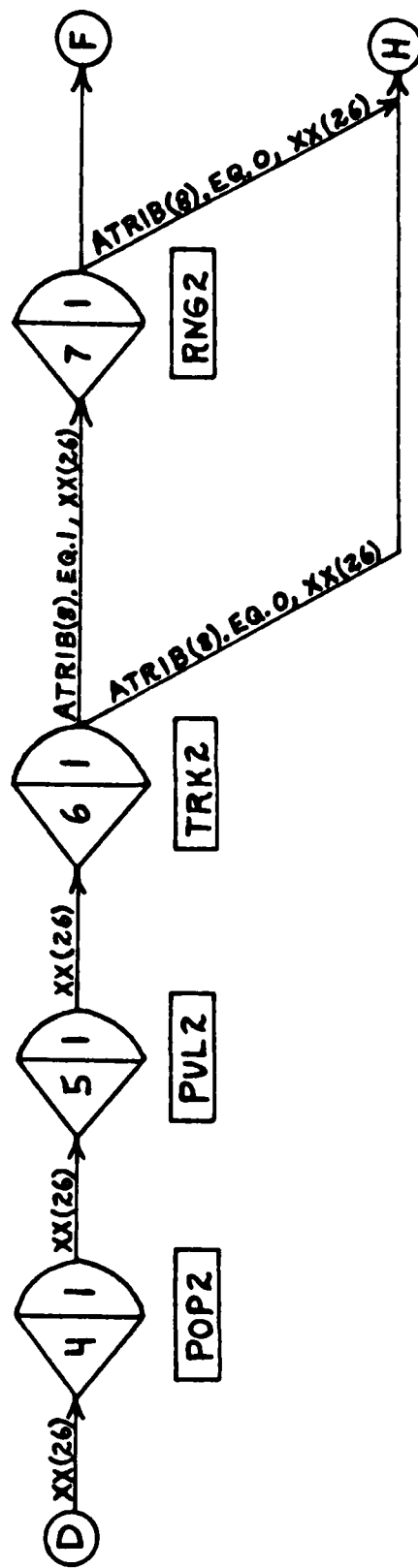
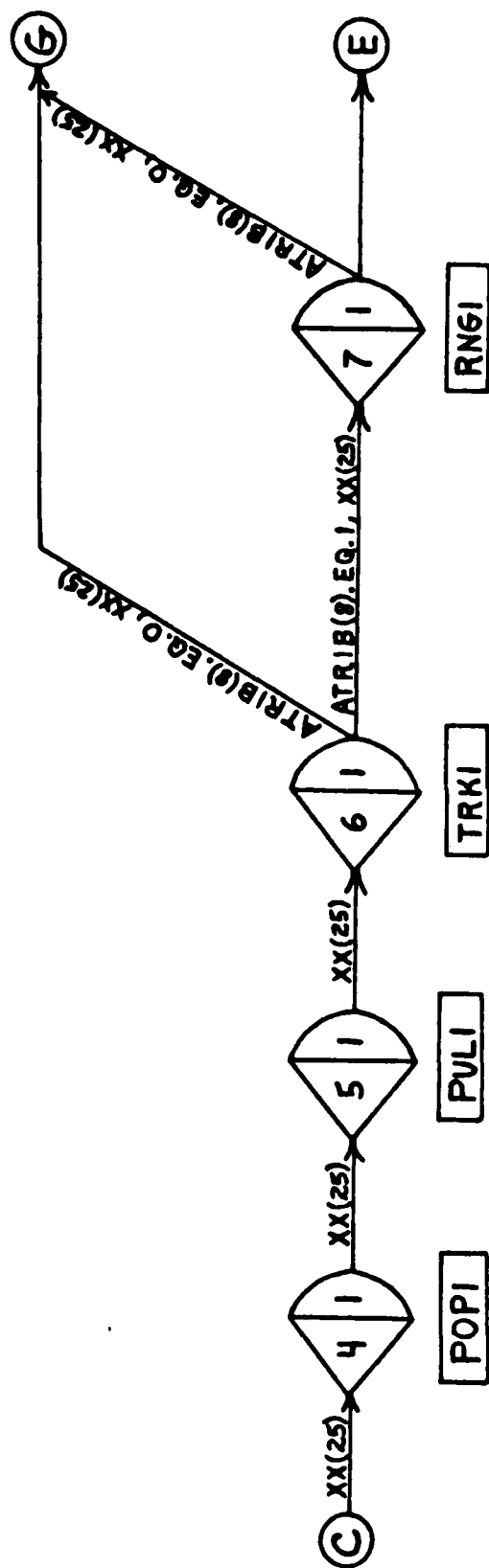
13. Hill, J. I. Visual and Optically Aided Visual Terrain Search Rates as Derived From Land Mine Detection and Tank vs AT Weapons Test. Proceedings U. S. Army Operations Research Symposium, AORS XIII, October 1974.
14. Himes, David A. "A Comparison of TAGSEM and Red Flag." Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, March 1979.
15. IAG-13-U078. Soviet Army Operations. Arlington Hall Station, Arlington, Virginia: U. S. Army Intelligence and Threat Analysis Center, April 1978.
16. Law, Averill M. and W. David Kelton. Simulation Modeling and Analysis. New York: McGraw-Hill Book Company, 1982.
17. Leedhom, Dennis K. and Arnold R. Thomas. "A Simulation Study of the Force Mix Problem in Close Air Support Operations." Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, June 1973.
18. Leek, Warren J. and Richard W. Schmitt. "Survivability Study of a FLIR Equipped Fighter on a Night Penetration of a Soviet Army." Master of Science Thesis. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, March 1981.
19. Pritsker, A. Alan B. and Claude Dennis Pegden. Introduction to Simulation and SLAM. New York: John Wiley and Sons, 1979.
20. Robinson, Clarence A., Jr. "Increasing Soviet Offensive Threat." Aviation Week and Space Technology, 107 (5): 38-46 (August 1, 1977).
21. Saye, Jeremy G. "Close Air Support in Modern Warfare," Air University Review, 31 (2): 3-21 (January - February 1980).
22. Shannon, Robert E. Systems Simulation--The Art and Science. Englewood Cliffs, New Jersey: Prentice Hall, Inc., 1975.
23. Stimpson, David A. F-16 Training Program Manager, Fighter Training Division, Headquarters Tactical Air Command (telephone conversation). Langley AFB, Virginia, 2 December 1982.
24. TACH 2-1. Tactical Air Operations. Langley Air Force Base, Virginia: Headquarters Tactical Air Command, April 1978.

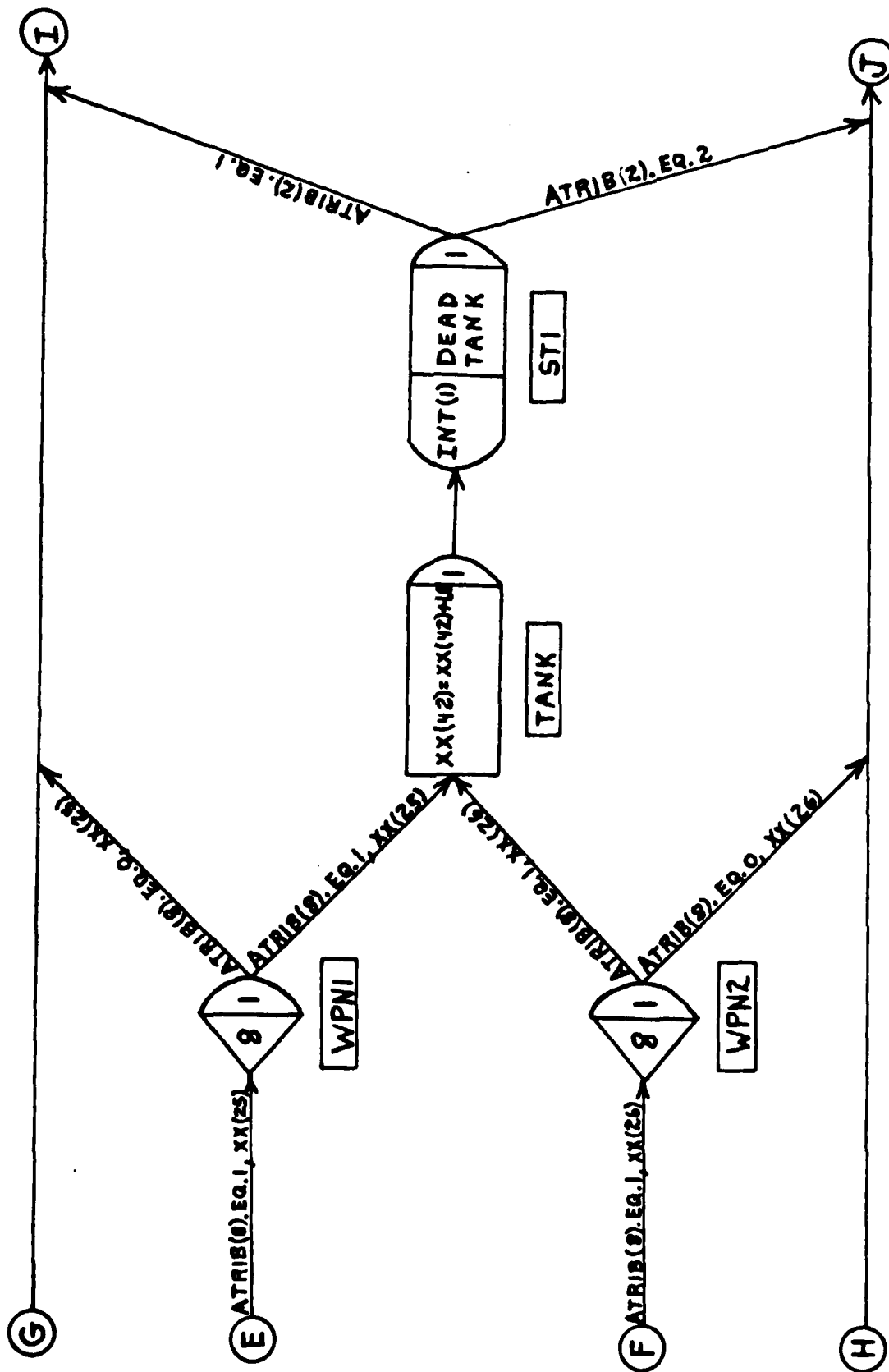
Appendix A

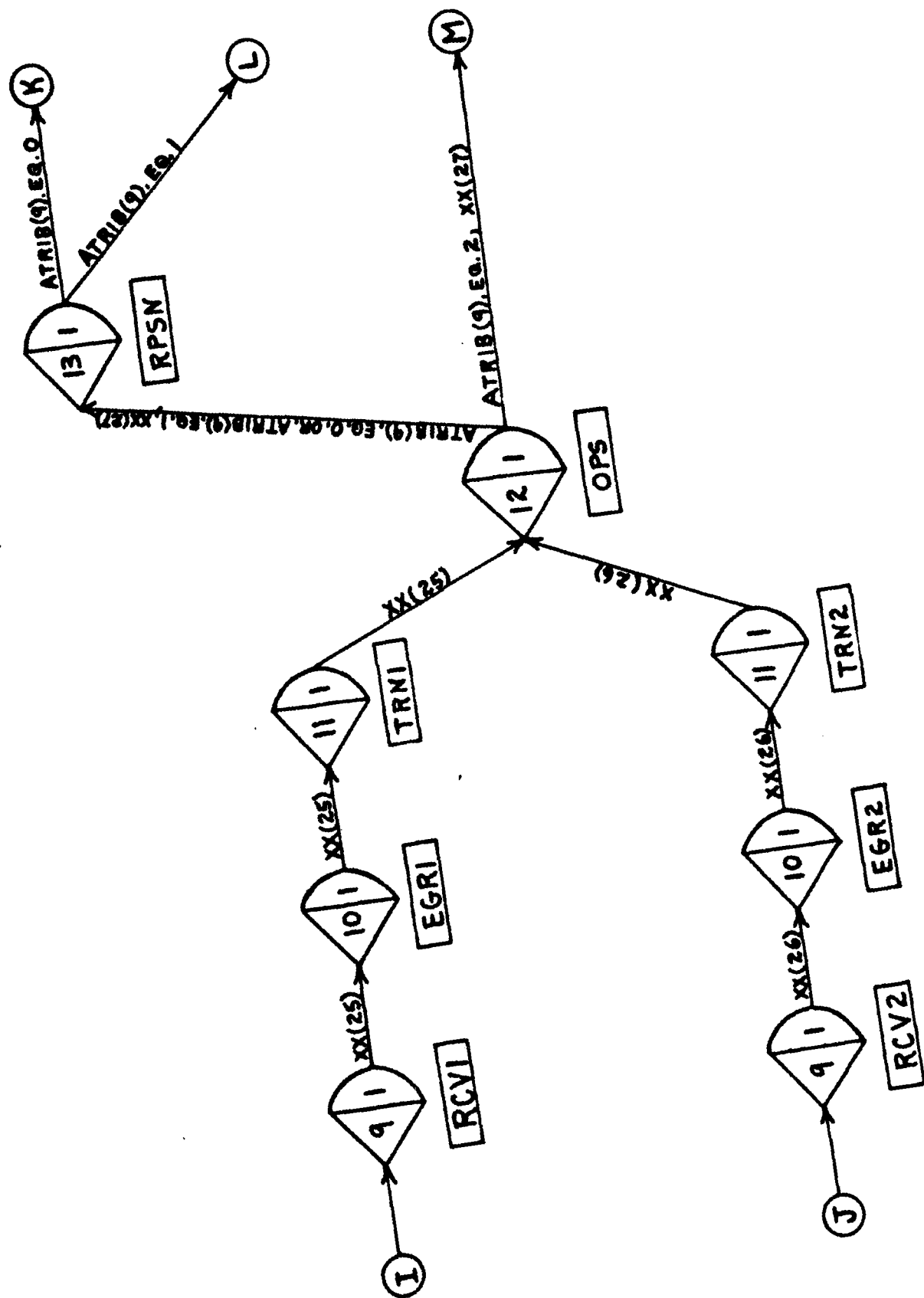
SLAM Network

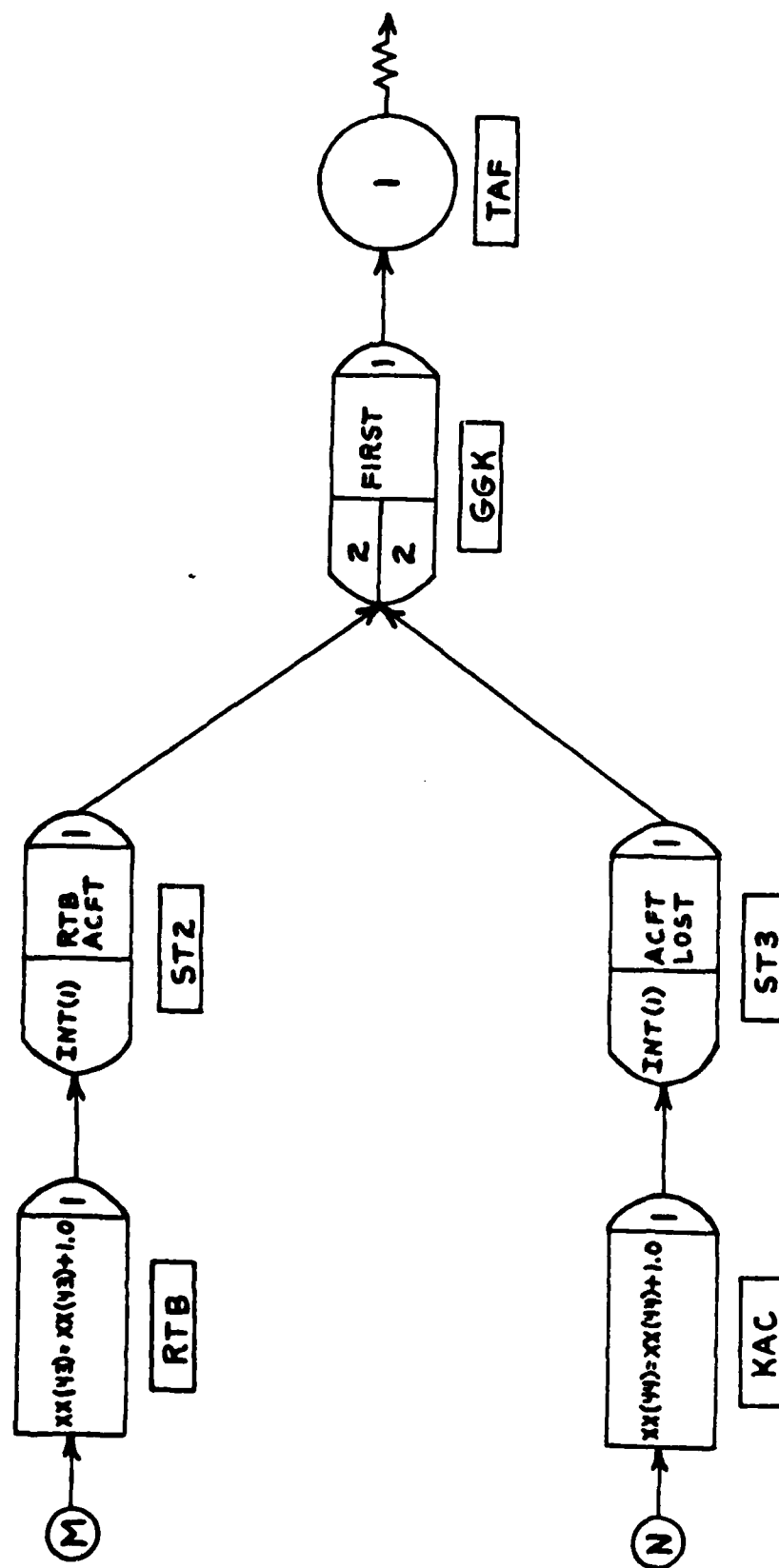












Appendix B

SLAM State Variables

SSUse

1	Aircraft # 1 X-coordinate
2	Aircraft # 2 X-coordinate
3	Aircraft # 1 Y-coordinate
4	Aircraft # 2 Y-coordinate
5	Aircraft # 1 altitude
6	Aircraft # 2 altitude
7	Aircraft # 1 heading
8	Aircraft # 2 heading

Appendix C

SLAM Global Variables

<u>XX</u>	<u>Use</u>
1	Fuel in seconds
2	30mm gun rounds
3	30mm gun firing rate (2100 on 4200 rpm)
4	Maverick missile load
5	30mm gun firing duration in seconds
6	30mm gun firing range in meters
7	True airspeed in knots (KTAS)
8	Desired low level altitude in meters
9	Aircraft G loading in unaccelerated level flight
10	Aircraft #1 effective airspeed in meters/sec (0 if aircraft is in holding pattern)
11	Aircraft #2 effective airspeed in meters/sec (0 if aircraft is in holding pattern)
12	Contact point (CP) X-coordinate
13	Contact point (CP) Y-coordinate
14	Initial point (IP) X-coordinate
15	Initial point (IP) Y-coordinate
16	Aircraft #1 target X-coordinate
17	Aircraft #2 target X-coordinate
18	Aircraft #1 target Y-coordinate
19	Aircraft #2 target Y-coordinate
20	Maximum zone of enemy advance Y-coordinate
21	Minimum zone of enemy advance Y-coordinate
22	Maximum enemy main attack Y-coordinate
23	Minimum enemy main attack Y-coordinate
24	Flying time from CP to IP

25 Activity times for aircraft #1 during attack profile
26 Activity times for aircraft #2 during attack profile
27 Flying time required after the fuel and weapons check
to return to the IP or CP
28-29 Not used
30 Standard deviation of the aircraft heading distribution
in degrees
31 Standard deviation of the distance from the IP to
the pop up point (PUP) as a fraction of the computed
distance
32 Standard deviation of the normally distributed
threat array Y-coordinate
33 Mean value of both the threat array and aircraft
ground target Y-coordinate normal distribution
34 Minimum value for the SAM A/B X-coordinate uniform
distribution
35 Maximum value for the SAM A/B X-coordinate uniform
distribution
36 Standard deviation of the normally distributed
aircraft ground target Y distribution
37 Minimum value for the aircraft ground target X-
coordinate uniform distribution
38 Maximum value for the aircraft ground target X-
coordinate uniform distribution
39-41 Not used
42 Cumulative number of destroyed aircraft ground targets
43 Cumulative number of aircraft returning to base (RTE)

44 Cumulative number of aircraft shot down
45 Not used
46 Aircraft desired attack dive angle in degrees
47 Aircraft desired attack track-point slant range in
meters
48 Aircraft desired attack offset angle in degrees
49 Not used
50 Magnetic bearing from an aircraft to any other point
as determined in subroutine GEOM
51 Aspect angle between an aircraft and any other point
as determined in subroutine GEOM
52 Ground range from an aircraft to any other point as
determined in subroutine GEOM
53 Slant range from an aircraft to any other point as
determined in subroutine GEOM
54 Predominate aircraft heading during holding at the CP
55 Early warning (EW) radar flag
1 - EW operational
0 - No EW
56 Aircraft #1 attack apex altitude
57 Aircraft #2 attack apex altitude
58 Aircraft #1 threat search flag
1 - Threats can search for aircraft
0 - Threats cannot search for aircraft
59 Aircraft #2 threat search flag
1 - Threats can search for aircraft
0 - Threats cannot search for aircraft
60 Aircraft #1 G load

- 61 Aircraft #2 G load
- 62 Aircraft #1 kill or RTB flag
- 1 - Aircraft has been killed or returned to base
 - 0 - Aircraft is still in system
- 63 Aircraft #2 kill or RTB flag
- 1 - Aircraft has been killed or returned to base
 - 0 - Aircraft is still in system
- 64 Maximum number of AAA simultaneously paired against each aircraft
- 65 Maximum number of SAMs simultaneously paired against each aircraft
- 66 Threat disengage flag
- 1 - Do not disengage
 - 0 - Disengage if outside of maximum range and aspect angle is greater than 90 degrees
- 67 AAA threat flag
- 0 - AAA included in threat scenario
 - 3 - AAA excluded
- 68 SAM A threat flag
- 0 - SAM A included in threat scenario
 - 3 - SAM A excluded
- 69 SAM B threat flag
- 0 - SAM B included in threat scenario
 - 3 - SAM B excluded
- 70 SAM C threat flag
- 0 - SAM C included in threat scenario
 - 3 - SAM C excluded
- 71 Number of AAA committed against aircraft #1
- 72 Number of AAA committed against aircraft #2
- 73 Number of SAMs committed against aircraft #1
- 74 Number of SAMs committed against aircraft #2

- 75 Minimum probability of kill (PK) required for threat employment against aircraft #1
- 76 Minimum probability of kill (PK) required for threat employment against aircraft #2
- 77 Minimum probability of kill (PK) required for threat employment against aircraft above low level altitude
- 78 Minimum probability of kill (PK) required for threat employment against aircraft at low level altitude
- 79 Number of AAA in threat array
- 80 Number of SAM A in threat array
- 81 Number of SAM B in threat array
- 82 Number of SAM C in threat array
- 83 Policy number for SPSS data

Appendix D

SLAM File Structure

<u>File</u>	<u>Use</u>
1	Radar cross section (RCS) data
2	Threat file
3	Forward air controller (FAC) briefing queue
4	Event calendar

Appendix E

Attribute Listing

File 1

<u>Attribute</u>	<u>Use</u>
1	Aspect angle
2	Radar cross-section for AAA
3	Radar cross-section for SAM A
4	Radar cross-section for SAM B
5	Radar cross-section for SAM C

File 2

<u>Attribute</u>	<u>Use</u>
1	Threat number (1-44)
2	Type of threat 1 - AAA 2 - SAM A 3 - SAM B 4 - SAM C
3	Threat X-coordinate
4	Threat Y-coordinate
5	Threat radar transmitter power in db
6	Threat radar antenna gain in db
7	Maximum weapon range in meters
8	Minimum weapon range in meters
9	Minimum engagement altitude in meters
10	Lethal radius in meters
11	Minimum acquisition and tracking time in seconds
12	Maximum acquisition and tracking time in seconds

- 13 Missile velocity in meters/sec
- 14 Confounding delay in seconds
- 15 Jammer effective radiated power (ERP) in db
- 16 Multipath angle
- 17 Aircraft working designator
 - 0 - Not engaged
 - 1 - Engaged with aircraft #1
 - 2 - Engaged with aircraft #2

Aircraft entity

<u>Attribute</u>	<u>Use</u>
1	Mark time
2	Aircraft call sign
3	Fuel in seconds
4	30mm gun rounds available
5	Maverick missiles available
6	Airspeed in meters/sec
7	Weapons employment flag <ul style="list-style-type: none"> 1 - Maverick 0 - Gun
8	Attack status flag <ul style="list-style-type: none"> 1 - Continue attack 0 - Abort attack
9	Reposition flag <ul style="list-style-type: none"> 2 - Return to base 1 - Return to IP 0 - Return to CP
10	Number of targets in target area
11	Roll - in direction <ul style="list-style-type: none"> 2 - left roll-in 1 - right roll-in

12-17 Not used

18 Type of entity

 0 - Main network

 1 - THRT loop

Aircraft/Threat entity

<u>Attribute</u>	<u>Use</u>
1	Type of threat (1-44)
2	Aircraft call sign
3	Threat X-coordinate
4	Threat Y-coordinate
5	Threat radar transmitter power in db
6	Threat radar antenna gain in db
7	Maximum weapon range in meters
8	Minimum weapon range in meters
9	Minimum engagement altitude in meters
10	Lethal radius in meters
11	Missile velocity in meters/sec
12	Confounding delay in seconds
13	Jammer effective power (ERP in db)
14	Multipath angle
15	Slant range from initial missile time of flight (TOF) calculation computed in event 15
16	Cumulative missile time of flight (TOF)

17 Flag for event calling subroutine

PKILL

0 - event 15

1 - event 16

18 Type of entity

0 - Main network entity

1 - Threat entity

2 - Aircraft/Threat entity

Appendix F

SLAM Computer Model

DWN,CM175000,T300,IO150. T820369,NEAL,4438
 ATTACH,PROCFIL,ID=A810171,SN=ASDAD.
 BEGIN,NOSFILE.
 GET,THESIS1,ID=DNEAL.
 FTN5,I=THESIS1,ANSI=0,LO=0.
 ATTACH,PROCFIL,SLAMPROC,ID=AFIT,SN=AFIT.
 BEGIN,SLAMII,,M=LGO,PL=50000.
 REWIND,TAPE8.
 REPLACE,TAPE8,ID=DNEAL.
 ROUTE,TAPE8,DC=PR,TID=AF,FID=DWN,ST=ANY.
 GEN,NEAL AND KIZER,THESIS,10/20/82,20,YES;
 LIMITS,3,18,130;
 PRIORITY/1,LVF(1)/2,LVF(1);
 INITIALIZE,0,2000;
 CONTINUOUS,0,8,.1,5,10,W,.001,.001;
 NETWORK;
 CREATE,,,1,,1;
 ACT,,,ORBT;
 ORBT GOON,2;
 ACT,,,GARY;
 ACT,,,DON;
 GARY ASSIGN,ATTRIB(2)=1,ATTRIB(3)=XX(1),
 ATTRIB(4)=XX(2),ATTRIB(5)=XX(4),
 ATTRIB(6)=XX(7)/1.943,ATTRIB(7)=1,
 ATTRIB(8)=0,ATTRIB(9)=0,
 ATTRIB(10)=0,ATTRIB(11)=2,1;
 ACT,,,KILL;
 DON ASSIGN,ATTRIB(2)=2,ATTRIB(3)=XX(1),
 ATTRIB(4)=XX(2),ATTRIB(5)=XX(4),
 ATTRIB(6)=XX(7)/1.943,ATTRIB(7)=1,
 ATTRIB(8)=0,ATTRIB(9)=0,
 ATTRIB(10)=0,ATTRIB(11)=2,1;
 ACT,,,KILL;
 KILL GOON,2;
 ACT,,,FAC;
 ACT,,,THRT;
 FAC QUEUE(3),,2;
 ACT(1)/1,UNFRM(30,120,1),,CP;
 CP EVENT,1,1;
 ACT,XX(24),,IP;
 IP EVENT,2,1;
 ACT,,ATTRIB(2).EQ.1,ING1;
 ACT,,ATTRIB(2).EQ.2,ING2;
 ING1 EVENT,3,1;
 ACT,XX(25),,POP1;
 POP1 EVENT,4,1;
 ACT,XX(25),,PUL1;
 PUL1 EVENT,5,1;
 ACT,XX(25),,TRK1;
 TRK1 EVENT,6,1;

ACT,XX(25),ATRI(8).EQ.0,RCV1;
 ACT,XX(25),ATRI(8).EQ.1,RNG1;
 RCV1 EVENT,9,1;
 ACT,XX(25),,EGR1;
 EGR1 EVENT,10,1;
 ACT,XX(25),,TRN1;
 TRN1 EVENT,11,1;
 ACT,XX(25),,OPS;
 OPS EVENT,12,1;
 ACT,XX(27),ATRI(9).EQ.0.OR.ATRI(9).EQ.1,RPSN;
 ACT,XX(27),ATRI(9).EQ.2,RTB;
 RPSN EVENT,13,1;
 ACT,,ATRI(9).EQ.0,FAC;
 ACT,,ATRI(9).EQ.1,IP;
 RTB ASSIGN,XX(43)=XX(43)+1.0,1;
 ACT,,ST2;
 ST2 COLCT,INT(1),RTB ACFT,,1;
 ACT,,GCK;
 GCK ACCUMULATE,2,2,FIRST,1;
 ACT,,TAF;
 RNG1 EVENT,7,1;
 ACT,XX(25),ATRI(8).EQ.0,RCV1;
 ACT,XX(25),ATRI(8).EQ.1,WPN1;
 WPN1 EVENT,8,1;
 ACT,XX(25),ATRI(8).EQ.0,RCV1;
 ACT,XX(25),ATRI(8).EQ.1,TANK;
 TANK ASSIGN,XX(42)=XX(42)+1.0,1;
 ACT,,ST1;
 ST1 COLCT,INT(1),DEAD TANK,,1;
 ACT,,ATRI(2).EQ.1,RCV1;
 ACT,,ATRI(2).EQ.2,RCV2;
 RCV2 EVENT,9,1;
 ACT,XX(26),,EGR2;
 EGR2 EVENT,10,1;
 ACT,XX(26),,TRN2;
 TRN2 EVENT,11,1;
 ACT,XX(26),,OPS;
 ING2 EVENT,3,1;
 ACT,XX(26),,POP2;
 POP2 EVENT,4,1;
 ACT,XX(26),,PUL2;
 PUL2 EVENT,5,1;
 ACT,XX(26),,TRK2;
 TRK2 EVENT,6,1;
 ACT,XX(26),ATRI(8).EQ.0,RCV2;
 ACT,XX(26),ATRI(8).EQ.1,RNG2;
 RNG2 EVENT,7,1;
 ACT,XX(26),ATRI(8).EQ.0,RCV2;
 ACT,XX(26),ATRI(8).EQ.1,WPN2;
 WPN2 EVENT,8,1;

SIMULATE;
FIN;


```
PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7,TAPE8)
```

```
DIMENSION NSET(10000)  
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,  
+NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),  
+TNEXT,TNOW,XX(100)  
COMMON QSET(10000)  
EQUIVALENCE (NSET(1),QSET(1))
```

```
NCRDR = 5  
NPRNT = 6  
NTAPE = 7  
NNSET = 10000  
CALL SLAM  
STOP  
END
```

SUBROUTINE STATE

```
COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,  
+NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),  
+TNEXT,TNOW,XX(100)  
COMMON/UCOM1/TRATE(2),ARATE(2)
```

```
DO 30 I = 1,2  
  IF (XX(I+61).EQ.0) THEN
```

* HEADING RATE EQUATIONS

```
  SS(I+6) = SSL(I+6) + DTNOW * TRATE(I)  
  IF (SS(I+6).LT.0.0) THEN  
    SS(I+6) = SS(I+6) + 360.0  
  ENDIF  
  IF (SS(I+6).GT.360.0) THEN  
    SS(I+6) = SS(I+6) - 360.0  
  ENDIF
```

* ALTITUDE RATE EQUATIONS

```
  SS(I+4) = SSL(I+4) + DTNOW * ARATE(I)  
  IF (SS(I+4).LT.XX(8)) THEN  
    ARATE(I) = 0.0  
    SS(I+4) = XX(8)  
  ENDIF
```

* AIRCRAFT COORDINATES IN X AND Y DIRECTION

```
  SS(I) = SSL(I) + DTNOW * SQRT((XX(I+9)**2)-ARATE(I)**2) *  
+  COSD(90.0-SS(I+6))  
  SS(I+2) = SSL(I+2) + DTNOW * SQRT((XX(I+9)**2)-ARATE(I)**2) *
```

```

+          SIND(90.0-SS(I+6))

*      MINIMUM PROBABILITIES OF KILL

          IF (SS(I+4).GT.XX(8)) THEN
              XX(I+74) = XX(77)
          ELSE
              XX(I+74) = XX(78)
          ENDIF
      ENDIF
30  CONTINUE
    RETURN
    END

    SUBROUTINE INTLC

        COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
        +NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
        +TNEXT,TNOW,XX(100)
        COMMON/UCOM1/TRATE(2),ARATE(2)
        COMMON/UCOM2/A(18),B(18)
        DIMENSION RCS(37,5)
        DATA A,B/18*0.0,18*0.0/

*      RCS CONTAINS RADAR CROSS SECTION VALUES TO BE PLACED
*      IN FILE 1.

        DATA ((RCS(IR,IC),IC=1,5),IR=1,37)/0,8.2,8.2,3.6,3.6,5,6.7,6.7,
        +0.4,0.4,10,1.9,1.9,2.55,2.55,15,3.48,3.48,3.03,3.03,20,
        +0.85,0.85,1.70,1.70,25,3.95,3.95,2.50,2.50,30,5.2,5.2,
        +10.65,10.65,35,-1.2,-1.2,7.95,7.95,40,1.7,1.7,3.45,3.45,
        +45,6.35,6.35,3.7,3.7,50,3.1,3.1,-0.95,-0.95,55,1.0,1.0,
        +0.65,-0.65,60,1.9,1.9,-0.95,-0.95,65,0.25,0.25,0.05,0.05,
        +70,8.19,8.19,8.45,8.45,75,13.43,13.43,14.55,14.55,80,
        +16.7,16.7,16.35,16.35,85,16.08,16.08,16.0,16.0,90,24.38,
        +24.38,24.98,24.98,95,19.23,19.23,19.95,19.95,100,16.58,
        +16.58,15.75,15.75,105,5.83,5.83,9.2,9.2,110,9.5,9.5,8.73,
        +8.73,115,6.2,6.2,3.65,3.65,120,7.85,7.85,2.33,2.33,125,
        +4.28,4.28,3.13,3.13,130,3.48,3.48,3.03,3.03,135,4.35,4.35,
        +1.08,-1.08,140,3.9,3.9,-2.6,-2.6,145,6.0,6.0,0.5,0.5,
        +150,5.23,5.23,0.55,0.55,155,6.93,6.93,0.43,0.43,160,2.95,
        +2.95,0.58,0.58,165,4.73,4.73,6.38,6.38,170,9.93,9.93,
        +6.53,6.53,175,13.5,13.5,8.85,8.85,180,15.05,15.05,9.48,
        +9.48/

        DO 35 IN = 1,37
            A(1) = RCS(IN,1)
            A(2) = RCS(IN,2)
            A(3) = RCS(IN,3)
            A(4) = RCS(IN,4)

```

```
      A(5) = RCS(IN,5)
      CALL FILEM(1,A)
35  CONTINUE
```

* INITIAL VALUES FOR GLOBAL VARIABLES

```
XX(1) = 1800.0
XX(2) = 1350.0
XX(3) = 4200.0
XX(5) = 1.0
XX(6) = 609.6
XX(8) = 30.48
XX(9) = 1.0
XX(10) = 0.0
XX(11) = 0.0
XX(12) = 0.0
XX(13) = 16000.0
XX(14) = 8000.0
XX(15) = 16000.0
XX(20) = 28000.0
XX(21) = 4000.0
XX(22) = 21000.0
XX(23) = 11000.0
XX(30) = 1.0
XX(31) = 0.05
XX(32) = (XX(22)-XX(23)) / 2.0
XX(33) = (XX(20)+XX(21)) / 2.0
XX(34) = 17000.0
XX(35) = 27000.0
XX(36) = 5000.0
XX(37) = 15000.0
XX(42) = 0.0
XX(43) = 0.0
XX(44) = 0.0
XX(46) = 5.0
XX(47) = 3706.4
XX(48) = 30.0
XX(50) = 0.0
XX(51) = 0.0
XX(52) = 0.0
XX(53) = 0.0
XX(54) = 90.0
XX(58) = 0
XX(59) = 0
XX(62) = 0
XX(63) = 0
XX(66) = 0
XX(67) = 0
XX(68) = 0
XX(69) = 0
```

XX(70) = 0
XX(71) = 0
XX(72) = 0
XX(73) = 0
XX(74) = 0
XX(77) = 0.1
XX(78) = 0.5
XX(82) = 3

* INITIAL VALUES OF STATE VARIABLES

DO 40 I = 1,2
SS(I) = XX(12)
SS(I+2) = XX(13)
SS(I+4) = XX(8)
SS(I+6) = XX(54)
TRATE(I) = 0.0
ARATE(I) = 0.0

40 CONTINUE

* CONSTRUCT AND POSITION AAA THREATS

DO 45 J = 1,XX(79)
B(1) = J
B(2) = 1
NROW1 = NINT(XX(79) / 2.0)
IF (J.LE.NROW1) THEN
B(3) = 16000.0
ELSE
B(3) = 17000.0
ENDIF
B(4) = RNORM(XX(33),XX(32),1)
B(5) = 50.9
B(6) = 40.0
B(7) = 2990.0
B(8) = 0.0
B(9) = 0.0
B(10) = 0.0
B(11) = 6.0
B(12) = 25.0
B(13) = 0.0
B(14) = 30.0
B(15) = 32.3
B(16) = 0.0
B(17) = XX(67)
B(18) = 0
CALL FILEM(2,B)

45 CONTINUE

* CONSTRUCT AND POSITION SAM-A THREATS

```

DO 50 J = 17,XX(80)+16
  B(1) = J
  B(2) = 2
  B(3) = UNFRM(XX(34),XX(35),1)
  B(4) = RNORM(XX(33),XX(32),1)
  B(5) = 50.0
  B(6) = 43.0
  B(7) = 10200.0
  B(8) = 2038.0
  B(9) = 45.0
  B(10) = 22.0
  B(11) = 10.0
  B(12) = 23.0
  B(13) = 525.0
  B(14) = 30.0
  B(15) = 29.6
  B(16) = 0.25
  B(17) = XX(68)
  B(18) = 0
  CALL FILEM(2,B)

```

50 CONTINUE

* CONSTRUCT AND POSITION SAM-B THREATS

```

DO 55 J = 37,XX(81)+36
  B(1) = J
  B(2) = 3
  B(3) = UNFRM(XX(34),XX(35),1)
  B(4) = RNORM(XX(33),XX(32),1)
  B(5) = 53.0
  B(6) = 41.0
  B(7) = 22250.0
  B(8) = 4076.6
  B(9) = 15.0
  B(10) = 26.2
  B(11) = 17.0
  B(12) = 38.0
  B(13) = 599.0
  B(14) = 30.0
  B(15) = 29.6
  B(16) = 0.15
  B(17) = XX(69)
  B(18) = 0
  CALL FILEM(2,B)

```

55 CONTINUE

* CONSTRUCT AND POSITION SAM-C THREATS

```

DO 60 J = 42,XX(82)+41

```

```

      B(1) = J
      B(2) = 4
      B(3) = 35000.0
      B(4) = RNORM(XX(33),XX(32),1)
      B(5) = 50.0
      B(6) = 42.0
      B(7) = 74150.0
      B(8) = 7968.0
      B(9) = 305.0
      B(10) = 43.6
      B(11) = 12.0
      B(12) = 26.0
      B(13) = 759.0
      B(14) = 15.0
      B(15) = 29.6
      B(16) = 0.35
      B(17) = XX(70)
      B(18) = 0
      CALL FILEM(2,B)
60  CONTINUE
      RETURN
      END

      SUBROUTINE EVENT(IX)

      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
+NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
+TNEXT,TNOW,XX(100)
      COMMON/UCOM1/TRATE(2),ARATE(2)
      COMMON/UCOM2/A(18),B(18)
      DIMENSION NSET(1)
      COMMON QSET(1)
      EQUIVALENCE (NSET(1),QSET(1))

      I = ATRIB(2)
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17),IX

*   EVENT 1

*   REPRESENTS THE CONTACT POINT AND IS USED TO ASSIGN TARGET
*   COORDINATES.  ALSO, AIRSPEED IS ESTABLISHED, AND AIRCRAFT
*   IS GIVEN PROPER TIME, HEADING, AND G LEVEL TO FLY TO THE
*   IP.  ASSIGNS NUMBER OF TARGETS IN TARGET AREA.

1   ATRIB(18) = 0
      XX(I+9) = ATRIB(6)
      CALL GEOM(XX(15),SS(I+2),XX(14),SS(I),SS(I+6),SS(I+4),XX(50),
+XX(51),XX(52),XX(53))
      XX(24) = XX(52) / XX(I+9)
      SS(I+6) = XX(50)

```

```

XX(I+15) = UNFRM(XX(37),XX(38),1)
XX(I+17) = RNORM(XX(33),XX(36),1)
TGTS = DRAND(1)
IF (TGTS.LE.0.50) THEN
  ATRIB(10) = 1
ELSE
  ATRIB(10) = 2
ENDIF
XX(I+59) = XX(9)
RETURN

```

★ EVENT 2

★ REPRESENTS THE IP AND IS USED TO COMPUTE THE HEADING AND
 ★ DISTANCE TO THE PULL UP POINT. ALSO, ATTACK GEOMETRY IS
 ★ COMPUTED. AIRCRAFT IS TURNED TO THE PROPER HEADING FOR
 ★ THE COMPUTED FLIGHT TIME TO THE PUP.

```

2 IF (ATLIB(5).EQ.0.0) THEN
  FINAL = 1853.2
ELSE
  FINAL = XX(47)
ENDIF
APEX = SIND(XX(46)) * FINAL
XX(I+55) = APEX - SS(I+4)
TRAD = (XX(I+9)**2) / (4.0 * 9.8)
SMDIS = TAND(XX(48)/2.0) * TRAD
TDIS = (COSD(XX(46)) * FINAL) + SMDIS
D = 180.0 - XX(48)
CALL GEOM(XX(I+17),SS(I+2),XX(I+15),SS(I),SS(I+6),SS(I+4),
+XX(50),XX(51),XX(52),XX(53))
F = ASIN((TDIS*SIND(D)) / XX(52)) * 57.29578
E = 180.0 - (D + F)
RNG = SIND(E) * (XX(52) / SIND(D))
PUP = RNG - SMDIS - (XX(I+55) / TAND(XX(46) + 5.0))
IF (XX(I+17).GT.XX(15)) THEN
  ATRIB(11) = 2
  SS(I+6) = RNORM(XX(50),XX(30),1) + F
ELSE
  ATRIB(11) = 1
  SS(I+6) = RNORM(XX(50),XX(30),1) - F
ENDIF
SD = PUP * XX(31)
RUNIN = RNORM(PUP,SD,1)
XX(I+24) = RUNIN / XX(I+9)
RETURN

```

★ EVENT 3

★ SETS THE INGRESS G LEVEL AND KEYS THE THREATS TO START

```

*   SEARCHING FOR AIRCRAFT.

3   XX(I+57) = 1
    XX(I+59) = 2.0
    RETURN

*   EVENT 4

*   REPRESENTS THE PULL UP POINT AND IS USED TO CLIMB THE
*   AIRCRAFT TO THE DESIRED APEX ALTITUDE.

4   CDIS = XX(I+55) / SIND(XX(46) + 5.0)
    XX(I+24) = CDIS / XX(I+9)
    ARATE(I) = XX(I+55) / XX(I+24)
    XX(I+59) = 2.0
    RETURN

*   EVENT 5

*   REPRESENTS A 4G ROLL-IN TO ATTACK HEADING

5   ARATE(I) = 0.0
    XX(I+59) = 4.0
    TRAD = (XX(I+9)**2) / (XX(I+59) * 9.8)
    TRATE(I) = (XX(I+9) * 360.0) / (2.0 * 3.1416 * TRAD)
    XX(I+24) = XX(48) / TRATE(I)
    IF (ATRI(11).EQ.2) THEN
        TRATE(I) = TRATE(I) * (-1.0)
    ENDIF
    RETURN

*   EVENT 6

*   CHECKS TARGET BEARING AND RANGE TO DETERMINE IF THE ATTACK
*   SHOULD CONTINUE OR BE ABORTED.  FINAL HEADING CORRECTIONS ARE
*   MADE TO PLACE THE TARGET DIRECTLY IN FRONT OF THE AIRCRAFT.

6   CALL GEOM(XX(I+17),SS(I+2),XX(I+15),SS(I),SS(I+6),SS(I+4),
+XX(50),XX(51),XX(52),XX(53))
    DIFF = ABS(XX(50) - SS(I+6))
    IF (DIFF.GT.180.0) THEN
        DIFF = 360.0 - DIFF
    ENDIF
    IF ((DIFF.LE.30.0).AND.(XX(53).LE.(XX(47)+1853.2))) THEN
        ATRIB(8) = 1
    ELSE
        ATRIB(8) = 0
    ENDIF
    IF (ATRI(8).EQ.0) THEN
        TRATE(I) = 0.0

```



```

      XX(I+24) = 0.0
    ELSE
      IF (DIFF.GE.20.0) THEN
        XX(I+59) = 4.0
      ELSE
        XX(I+59) = 2.0
      ENDIF
      TRAD = (XX(I+9)**2) / (XX(I+59) * 9.8)
      TRATE(I) = (XX(I+9) * 360.0) / (2.0 * 3.1416 * TRAD)
      XX(I+24) = DIFF / TRATE(I)
      IF ((XX(50) - SS(I+6)).LT.0.0) THEN
        TRATE(I) = TRATE(I) * (-1.0)
      ENDIF
      IF (ABS(XX(50) - SS(I+6)).GT.180.0) THEN
        TRATE(I) = TRATE(I) * (-1.0)
      ENDIF
    ENDIF
  RETURN

```

* EVENT 7

* ESTABLISHES DIVE ANGLE AND CHECKS TO SEE IF THE DIVE ANGLE
 * IS WITHIN ALLOWABLE LIMITS. DETERMINES WEAPON TO EMPLOY
 * DEPENDENT ON SLANT RANGE, MAVERICK MISSILE LOCK ON TIME,
 * AND WEAPONS LOAD.

```

7   TRATE(I) = 0.0
    CALL GEOM(XX(I+17),SS(I+2),XX(I+15),SS(I),SS(I+6),SS(I+4),
+XX(50),XX(51),XX(52),XX(53))
    DANGL = ATAN(SS(I+4) / XX(53)) * 57.29578
    IF (DANGL.LE.10.0) THEN
      FRMIN = 457.2
      FRDES = XX(6)
    ELSE IF (DANGL.LE.20.0) THEN
      FRMIN = 762.0
      FRDES = XX(6) + 304.8
    ELSE IF (DANGL.LE.30.0) THEN
      FRMIN = 1066.8
      FRDES = XX(6) + 609.6
    ELSE
      FRMIN = 1371.6
      FRDES = XX(6) + 914.4
    ENDIF
    IF ((XX(53).LT.FRMIN).OR.(DANGL.GT.(XX(46) + 15.0))) THEN
      ATRIB(8) = 0
      XX(I+24) = 0.0
    ELSE
      ARATE(I) = (SS(I+4) / (XX(53) / XX(I+9))) * (-1.0)
      IF ((XX(53).GE.1219.0).AND.(ATRIB(5).GT.0.0)) THEN
        TLOCK = UNFRM(5.0,11.0,1)
      ENDIF
    ENDIF

```

```

SLR = XX(53) - (TLOCK * XX(I+9))
XX(I+59) = 1.0
IF (SLR.GE.1219.0) THEN
  ATRIB(8) = 1
  XX(I+24) = TLOCK
  ATRIB(7) = 1
ELSE IF (ATLIB(4).GT.0.0) THEN
  ATRIB(8) = 1
  XX(I+24) = (XX(53) - 1219.0) / XX(I+9)
  ATRIB(7) = 0
ELSE
  ATRIB(8) = 0
  XX(I+24) = (XX(53) - 1219.0) / XX(I+9)
ENDIF
ELSE IF (ATLIB(4).GT.0.0) THEN
  ATRIB(8) = 1
  XX(I+24) = 0.0
  ATRIB(7) = 0
ELSE
  ATRIB(8) = 0
  XX(I+24) = 0.0
ENDIF
ENDIF
RETURN

```

★ EVENT 8

★ REPRESENTS WEAPON FIRING, AND DETERMINES THE PROBABILITY
★ OF KILL FOR THE WEAPON EMPLOYED.

```

8 CALL GEOM(XX(I+17),SS(I+2),XX(I+15),SS(I),SS(I+6),SS(I+4),
+XX(50),XX(51),XX(52),XX(53))
IF (ATLIB(7).EQ.1) THEN
  PKM = DRAND(1)
  IF (PKM.LE.0.85) THEN
    ATRIB(8) = 1
    ATRIB(10) = ATRIB(10) - 1
  ELSE
    ATRIB(8) = 0
  ENDIF
  XX(I+24) = 0.0
  ATRIB(5) = ATRIB(5) - 1.0
ELSE
  XX(I+59) = 3.0
  IF (XX(53).LT.FRDES) THEN
    FRNG = XX(53)
    XX(I+24) = XX(5)
  ELSE
    FRNG = FRDES
    XX(I+24) = ((XX(53) - FRDES) / XX(I+9)) + XX(5)
  ENDIF
ENDIF

```

```

ENDIF
VI = 1005.84 + XX(I+9)
VF = VI * EXP(-0.00038 * FRNG)
TOF = 2631.58 * ((1.0 / VF) - (1.0 / VI))
SIG2 = 2 * 3.1416 * ((5.0 * FRNG / 1000.0)**2)
BMESS = (9.8 * (TOF**2))**2
PKSS = (12.24 / (SIG2 + 12.24)) * EXP(-0.5 * (BMESS /
+ (SIG2 + 12.24)))
RDS = (XX(3) * XX(5)) / 60.0
IF (ATTRIB(4).LT.RDS) THEN
    RDS = ATTRIB(4)
ENDIF
PKG = 1.0 - ((1.0 - PKSS)**RDS)
IF (DRAND(1).LE.PKG) THEN
    ATTRIB(8) = 1
    ATTRIB(10) = ATTRIB(10) - 1
ELSE
    ATTRIB(8) = 0
ENDIF
ATTRIB(4) = ATTRIB(4) - RDS
ENDIF
RETURN

```

★ EVENT 9

★ REPRESENTS ATTACK RECOVERY AND DESCENDS THE AIRCRAFT TO
★ THE LOW LEVEL ALTITUDE WHILE TURNING THE AIRCRAFT TO A
★ 270 DEGREE HEADING.

```

9 IF (SS(I+6).LE.90.0) THEN
    TDEG = 90.0 + SS(I+6)
ELSE IF (SS(I+6).LE.180.0) THEN
    TDEG = 90.0 + (180.0 - SS(I+6))
ELSE IF (SS(I+6).LE.270.0) THEN
    TDEG = 270.0 - SS(I+6)
ELSE
    TDEG = SS(I+6) - 270.0
ENDIF
IF (TDEG.GE.20.0) THEN
    XX(I+59) = 4.0
ELSE
    XX(I+59) = 2.0
ENDIF
TRAD = (XX(I+9)**2) / (XX(I+59) * 9.8)
TRATE(I) = (XX(I+9) * 360.0) / (2.0 * 3.1416 * TRAD)
XX(I+24) = TDEG / TRATE(I)
IF (ATTRIB(11).EQ.2) THEN
    TRATE(I) = TRATE(I) * (-1.0)
ENDIF
ARATE(I) = ((SS(I+4) - XX(8)) / XX(I+24)) * (-1.0)

```

```

RETURN

*   EVENT 10

*   COMPUTES THE DISTANCE AND TIME TO FLY TO THE SAFE AREA.

10  TRATE(I) = 0.0
    ARATE(I) = 0.0
    XX(I+59) = 2.0
    SS(I+4) = XX(8)
    SS(I+6) = 270.0
    SDIS = SS(I) - 12000.0
    IF (SDIS.GE.0.0) THEN
        XX(I+24) = SDIS / XX(I+9)
    ELSE
        XX(I+24) = 0.0
    ENDIF
    RETURN

*   EVENT 11

*   TURNS THE AIRCRAFT TO EITHER THE IP OR CP DEPENDING ON
*   THE FUTURE ATTACK OPTION.

11  IF (ATRI(10).GT.0) THEN
    CALL GEOM(XX(15),SS(I+2),XX(14),SS(I),SS(I+6),SS(I+4),
+   XX(50),XX(51),XX(52),XX(53))
    ELSE
    CALL GEOM(XX(13),SS(I+2),XX(12),SS(I),SS(I+6),SS(I+4),
+   XX(50),XX(51),XX(52),XX(53))
    ENDIF
    TDEG = ABS(XX(50) - SS(I+6))
    IF (TDEG.GE.20.0) THEN
        XX(I+59) = 4.0
    ELSE
        XX(I+59) = 2.0
    ENDIF
    TRAD = (XX(I+9)**2) / (XX(I+59) * 9.8)
    TRATE(I) = (XX(I+9) * 360.0) / (2.0 * 3.1416 * TRAD)
    BRNG = XX(50)
    GRNG = XX(52)
    HDNG = SS(I+6)
    DTIME = 0.0
65  ANGL = 90.0 - ABS(BRNG - HDNG)
    W = TRAD * SIND(ANGL)
    Z = TRAD - W
    U = TRAD * COSD(ANGL)
    Q = GRNG - U
    CORECT = ATAN(Z / Q) * 57.29578
    V = Q / COSD(CORECT)

```

```

DELTA = CORECT / TRATE(I)
DTIME = DTIME + DELTA
GRNG = V
HDNG = BRNG
BRNG = BRNG + CORECT
IF (CORECT.GT.1.0) THEN
  GO TO 65
ENDIF
XX(I+24) = (TDEG / TRATE(I)) + DTIME
IF ((XX(50) - SS(I+6)).LT.0.0) THEN
  TRATE(I) = TRATE(I) * (-1.0)
ENDIF
RETURN

```

★ EVENT 12

★ COMPUTES THE FLIGHT TIME TO THE IP OR CP AND CHECKS THE
★ FUEL REMAINING TO DETERMINE IF ANOTHER ATTACK IS
★ WARRANTED. ALSO, THE WEAPONS LOAD IS CHECKED TO DETERMINE
★ THE FEASIBILITY OF ANOTHER ATTACK. IF FUEL AND WEAPONS
★ ARE AVAILABLE, THE AIRCRAFT RETURNS TO THE IP OR CP,
★ ELSE THE AIRCRAFT RETURNS TO BASE. IN ADDITION, THE
★ THREATS DISCONTINUE THEIR SEARCH FOR THE EGRESSING AIR-
★ CRAFT.

```

12  TRATE(I) = 0.0
    XX(I+59) = XX(9)
    IF (ATRI(10).GT.0) THEN
      CALL GEOM(XX(15),SS(I+2),XX(14),SS(I),SS(I+6),SS(I+4),
+ XX(50),XX(51),XX(52),XX(53))
      RTIME = XX(52) / XX(I+9)
    ELSE
      CALL GEOM(XX(13),SS(I+2),XX(12),SS(I),SS(I+6),SS(I+4),
+ XX(50),XX(51),XX(52),XX(53))
      RTIME = (XX(52) / XX(I+9)) + 120.0
    ENDIF
    ETIME = (TNOW + RTIME) - ATRI(1)
    IF ((ETIME.GE.ATRI(3)).OR.((ATRI(4).LE.35.0).AND.
+ (ATRI(5).EQ.0.0))) THEN
      ATRI(9) = 2
      XX(27) = 0.0
      XX(I+61) = 1
      NRTB = MMFE(NCLNR)
70  A2 = QSET(NRTB+2)
      NXT = NSUCR(NRTB)
      IF (A2.EQ.ATRI(2)) THEN
        A18 = QSET(NRTB+18)
        IF (A18.EQ.1) THEN
          CALL ULINK(-NRTB,NCLNR)
        ENDIF
      ENDIF
    ENDIF

```

```

ENDIF
NRTB = NXT
IF (NRTB.GT.0) THEN
  GO TO 70
ENDIF
ELSE IF (ATBIB(10).GT.0) THEN
  ATBIB(9) = 1
  XX(27) = XX(52) / XX(I+9)
ELSE
  ATBIB(9) = 0
  XX(27) = XX(52) / XX(I+9)
ENDIF
XX(I+57) = 0
NSAFE = MMFE(NCLNR)
73 AA2 = QSET(NSAFE+2)
AA17 = QSET(NSAFE+17)
AA19 = QSET(NSAFE+19)
NXXT = NSUCR(NSAFE)
IF ((AA2.EQ.ATBIB(2)).AND.(AA19.EQ.15).AND.(AA17.EQ.2)) THEN
  CALL ULINK(-NSAFE,NCLNR)
  AA1 = QSET(NSAFE+1)
  A(1) = AA1
  A(2) = AA2
  CALL SCHDL(17,1.0,A)
  IF (AA1.LE.16) THEN
    XX(I+70) = XX(I+70) - 1
  ELSE
    XX(I+72) = XX(I+72) - 1
  ENDIF
ENDIF
NSAFE = NXXT
IF (NSAFE.GT.0) THEN
  GO TO 73
ENDIF
RETURN

*   EVENT 13

*   RESETS STATE VARIABLES FOR NEXT ATTACK AND RESETS AIRCRAFT
*   COORDINATES TO EITHER THE IP OR CP DEPENDING ON NEXT
*   ATTACK OPTION.

13 IF (ATBIB(9).EQ.0) THEN
  SS(1) = XX(12)
  SS(I+2) = XX(13)
  SS(I+4) = XX(8)
  SS(I+6) = XX(54)
  XX(I+9) = 0.0
ELSE
  SS(1) = XX(14)

```

```

        SS(I+2) = XX(15)
        SS(I+4) = XX(8)
        SS(I+6) = XX(54)
    ENDIF
    RETURN

*   EVENT 14

*   USED TO CALL SUBROUTINE THREAT AND STARTS THE THREATS
*   SEARCHING FOR AIRCRAFT.

14   ATRIB(18) = 1
      NUMQ = XX(I+70) + XX(I+72)
      MAXN = XX(64) + XX(65)
      IF ((XX(I+57).EQ.1).AND.(XX(I+61).EQ.0).AND.(NUMQ.LT.MAXN)) THEN
          CALL THREAT
      ENDIF
      RETURN

*   EVENT 15

*   DISCRETE EVENT SCHEDULED AFTER THREAT ACQUISITION AND
*   TRACKING TIME HAS ELAPSED. IT CHECKS AIRCRAFT/THREAT
*   GEOMETRIC RELATIONSHIPS. IF THREAT IS A AAA IT CALLS
*   SUBROUTINE PKILL TO DETERMINE FEASIBILITY OF SHOT
*   ATTEMPT. IF THREAT IS A SAM IT DETERMINES MISSILE
*   TIME OF FLIGHT AND PROJECTED MISSILE IMPACT POINT.
*   SUBROUTINE PKILL IS CALLED TO DETERMINE FEASIBILITY
*   OF SHOT ATTEMPT.

15   CALL GEOM(ATRIB(4),SS(I+2),ATRIB(3),SS(I),SS(I+6),SS(I+4),
+XX(50),XX(51),XX(52),XX(53))
      ATRIB(17) = 0
      IF (XX(I+57).EQ.0) THEN
          IF (ATRIB(1).LE.16) THEN
              XX(I+70) = XX(I+70) - 1
          ELSE
              XX(I+72) = XX(I+72) - 1
          ENDIF
          CALL SCHDL(17,ATRIB(12),ATRIB)
      ELSE IF ((XX(53).LE.ATRIB(7)).AND.(XX(53).GE.ATRIB(8)).AND.
+ (SS(I+4).GE.ATRIB(9))) THEN
          IF (ATRIB(1).LE.16) THEN
              CALL PKILL
          ELSE
              VRATIO = XX(I+9) / ATRIB(11)
              ALPHA = ASIN(VRATIO * SIND(XX(51))) * 57.29578
              BRAVO = 180.0 - (XX(51) + ALPHA)
              FTIME = (SIND(XX(51)) * XX(53)) / (SIND(BRAVO) * ATRIB(11))
              ATRIB(15) = ATRIB(11) * FTIME
          
```

```

        ATRIB(16) = 0.0
        XX(53) = ATRIB(15)
        XX(51) = 180.0 - BRAVO
        CALL PKILL
    ENDIF
ELSE IF (XX(53).LT.ATRIB(8)) THEN
    CALL SCHDL(15,1.0,ATRIB)
ELSE
    IF ((XX(66).EQ.0).AND.(XX(51).GE.90.0)) THEN
        IF (ATRIB(1).LE.16) THEN
            XX(I+70) = XX(I+70) - 1
        ELSE
            XX(I+72) = XX(I+72) - 1
        ENDIF
        CALL SCHDL(17,ATRIB(12),ATRIB)
    ELSE
        CALL SCHDL(15,1.0,ATRIB)
    ENDIF
ENDIF
RETURN

```

* EVENT 16

* DISCRETE EVENT SCHEDULED FROM SUBROUTINE PKILL IF MISSILE
 * SHOT IS WARRANTED. ALLOWS FOR AIRCRAFT MANEUVERING PRIOR
 * TO MISSILE IMPACT AND RECOMPUTES MISSILE IMPACT GEOMETRY.
 * CALLS SUBROUTINE PKILL TO DETERMINE SUCCESS OR FAILURE
 * OF MISSILE ATTACK.

```

16 CALL GEOM(ATRIB(4),SS(I+2),ATRIB(3),SS(I),SS(I+6),SS(I+4),
+XX(50),XX(51),XX(52),XX(53))
    FRNG = ATRIB(11) * ATRIB(16)
    CRNG = XX(53) - FRNG
    IF (CRNG.LE.ATRIB(10)) THEN
        IF ((XX(53).GT.ATRIB(7)).OR.(XX(53).LT.ATRIB(8)).OR.
+ (SS(I+4).LT.ATRIB(9))) THEN
            XX(I+72) = XX(I+72) - 1
            CALL SCHDL(17,ATRIB(12),ATRIB)
        ELSE
            CALL PKILL
        ENDIF
    ELSE
        IF (XX(51).LE.90.0) THEN
            OVTK = ATRIB(11) + (XX(I+9) * COSD(XX(51)))
        ELSE
            OVTK = ATRIB(11) - (XX(I+9) * COSD(180.0 - XX(51)))
        ENDIF
        IF (CRNG.GT.OVTK) THEN
            DTOF = 1.0
        ELSE

```



```

      DTOF = 0.1
    ENDIF
    ATRIB(16) = ATRIB(16) + DTOF
    CALL SCHDL(16,DTOF,ATRIB)
  ENDIF
  RETURN

```

* EVENT 17

* REMOVES AIRCRAFT/THREAT ENTITIES FROM EVENT CALENDAR
 * AFTER THE CONFOUNDING DELAY HAS ELAPSED. FREES THE
 * THREAT TO SEARCH FOR ANOTHER AIRCRAFT.

```

17  NRANK = NFIND(1,2,1,0,ATRIB(1),0.0)
    NTHRT = LOCAT(NRANK,2)
    QSET(NTHRT+17) = 0
    RETURN
  END

```

SUBROUTINE GEOM(YP,YA,XP,XA,HEAD,ALT,BEAR,ASPECT,GR,SR)

* THIS SUBROUTINE TAKES THE X, Y, AND Z COORDINATES OF THE
 * AIRCRAFT AND THE X, Y, AND Z COORDINATES OF ANY OTHER POINT,
 * AND COMPUTES A BEARING, ASPECT ANGLE, GROUND RANGE, AND
 * SLANT RANGE TO THAT POINT.

```

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
+NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
+TNEXT,TNOW,XX(100)

```

```

YDIS = YP - YA
XDIS = XP - XA
IF (YDIS.EQ.0.0) THEN
  IF (XDIS.GT.0.0) THEN
    BEAR = 90.0
  ELSE IF (XDIS.LT.0.0) THEN
    BEAR = 270.0
  ELSE
    BEAR = 0.0
  ENDIF
ELSE IF (YDIS.LT.0.0) THEN
  IF (XDIS.GE.0.0) THEN
    BEAR = 180.0 - ABS(ATAN(XDIS / YDIS) * 57.29578)
  ELSE
    BEAR = 180.0 + ABS(ATAN(XDIS / YDIS) * 57.29578)
  ENDIF
ELSE
  IF (XDIS.GT.0.0) THEN
    BEAR = ATAN(XDIS / YDIS) * 57.29578
  ELSE

```

```

        BEAR = 360.0 - ABS(ATAN(XDIS / YDIS) * 57.29578)
    ENDIF
ENDIF
ASPECT = ABS(HEAD - BEAR)
IF (ASPECT.GT.180.0) THEN
    ASPECT = 360.0 - ASPECT
ENDIF
GR = SQRT((XDIS**2) + (YDIS**2))
SR = SQRT((GR**2) + (ALT**2))
RETURN
END

```

SUBROUTINE THREAT

```

*   COMMITS THREATS TO EACH AIRCRAFT BASED ON PROBABILITY
*   OF DETECTION.  IT ALSO LIMITS THE NUMBER OF THREATS
*   PAIRED ON EACH AIRCRAFT.

```

```

COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
+NCLNR,NCRDR,NPRNT,NNRUN,NSET,NTAPE,SS(100),SSL(100),
+TNEXT,TNOW,XX(100)
COMMON/UCOM2/A(18),B(18)
DIMENSION NSET(1)
COMMON QSET(1)
EQUIVALENCE (NSET(1),QSET(1))

```

```

I = ATTRIB(2)
NTHRT = MMFE(2)
75 IF (QSET(NTHRT+17).EQ.0) THEN
    B1 = QSET(NTHRT+1)
    IF ((B1.LE.16).AND.(XX(I+70).EQ.XX(64))) THEN
        GO TO 80
    ENDIF
    IF ((B1.GE.17).AND.(XX(I+72).EQ.XX(65))) THEN
        GO TO 80
    ENDIF
    B3 = QSET(NTHRT+3)
    B4 = QSET(NTHRT+4)
    CALL GEOM(B4,SS(I+2),B3,SS(I),SS(I+6),SS(I+4),XX(50),XX(51),
+ XX(52),XX(53))
    CALL MASK(PBSEE)
    ACQ = DRAND(1)
    IF (ACQ.LE.PBSEE) THEN
        B11 = QSET(NTHRT+11)
        B12 = QSET(NTHRT+12)
        QSET(NTHRT+17) = ATTRIB(2)
        IF (XX(55).EQ.1) THEN
            ATTM = UNFRM(B11,B12,1)
        ELSE
            ATTM = B12
        ENDIF
    ENDIF

```

```

ENDIF
B(1) = B1
B(2) = ATRIB(2)
B(3) = B3
B(4) = B4
B(5) = QSET(NTHRT+5)
B(6) = QSET(NTHRT+6)
B(7) = QSET(NTHRT+7)
B(8) = QSET(NTHRT+8)
B(9) = QSET(NTHRT+9)
B(10) = QSET(NTHRT+10)
B(11) = QSET(NTHRT+13)
B(12) = QSET(NTHRT+14)
B(13) = QSET(NTHRT+15)
B(14) = QSET(NTHRT+16)
B(17) = 2
B(18) = 2
CALL SCHDL(15,ATTM,B)
IF (B1.LE.16) THEN
  XX(I+70) = XX(I+70) + 1
ELSE
  XX(I+72) = XX(I+72) + 1
ENDIF
ENDIF
ENDIF
IF ((XX(I+70)+XX(I+72)).EQ.(XX(64)+XX(65))) THEN
  GO TO 85
ENDIF
80 NTHRT = NSUCR(NTHRT)
  IF (NTHRT.GT.0) THEN
    GO TO 75
  ENDIF
85 CONTINUE
  RETURN
  END

```

SUBROUTINE MASK(PBSEE)

* DETERMINES THE PROBABILITY OF AIRCRAFT DETECTION BY EACH
 * THREAT BASED ON AIRCRAFT ALTITUDE AND DISTANCE FROM THE
 * THREAT.

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
 +NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
 +TNEXT,TNOW,XX(100)

```

I = ATRIB(2)
IF (SS(I+4).LE.45.72) THEN
  IF (XX(52).LE.1829.0) THEN
    PBSEE = (-0.0001205 * XX(52)) + 1.0
  
```

```

ELSE IF (XX(52).LE.7925.0) THEN
  PBSEE = (-0.0000131 * XX(52)) + 0.34
ELSE
  PBSEE = 0.0
ENDIF
ELSE IF (SS(I+4).LE.76.2) THEN
  IF (XX(52).LE.3658.0) THEN
    PBSEE = (-0.0000625 * XX(52)) + 1.0
  ELSE IF (XX(52).LE.12192.0) THEN
    PBSEE = (-0.00001 * XX(52)) + 0.40
  ELSE
    PBSEE = 0.0
  ENDIF
ELSE IF (SS(I+4).LE.106.68) THEN
  IF (XX(52).LE.5182.0) THEN
    PBSEE = (-0.0000435 * XX(52)) + 1.0
  ELSE IF (XX(52).LE.12192.0) THEN
    PBSEE = (-0.0000068 * XX(52)) + 0.40
  ELSE
    PBSEE = 0.13
  ENDIF
ELSE IF (SS(I+4).LE.167.64) THEN
  IF (XX(52).LE.610.0) THEN
    PBSEE = 1.0
  ELSE IF (XX(52).LE.6705.0) THEN
    PBSEE = (-0.0000341 * XX(52)) + 1.025
  ELSE IF (XX(52).LE.12192.0) THEN
    PBSEE = (-0.0000045 * XX(52)) + 0.40
  ELSE
    PBSEE = 0.22
  ENDIF
ELSE IF (SS(I+4).LE.259.08) THEN
  IF (XX(52).LE.1829.0) THEN
    PBSEE = 1.0
  ELSE IF (XX(52).LE.6096.0) THEN
    PBSEE = (-0.0000246 * XX(52)) + 1.13
  ELSE IF (XX(52).LE.12192.0) THEN
    PBSEE = (-0.0000182 * XX(52)) + 1.0
  ELSE
    PBSEE = 0.27
  ENDIF
ELSE IF (SS(I+4).LE.381.0) THEN
  IF (XX(52).LE.2590.0) THEN
    PBSEE = 1.0
  ELSE IF (XX(52).LE.6096.0) THEN
    PBSEE = (-0.0000225 * XX(52)) + 1.18
  ELSE IF (XX(52).LE.12192.0) THEN
    PBSEE = (-0.0000128 * XX(52)) + 1.0
  ELSE
    PBSEE = 0.51
  ENDIF

```

```

ENDIF
ELSE
  IF (XX(52).LE.4572.0) THEN
    PBSEE = 1.0
  ELSE IF (XX(52).LE.12192.0) THEN
    PBSEE = (-0.0000155 * XX(52)) + 1.22
  ELSE
    PBSEE = 0.6
  ENDIF
ENDIF
RETURN
END

```

SUBROUTINE PKILL

- * COMPUTES THE PROBABILITY OF KILL FOR EACH AAA AND SAM
- * SHOT, AND UPDATES THE NUMBER OF THREATS ENGAGED ON EACH
- * TARGET BASED ON SHOT SUCCESS OR FAILURE.

```

COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
+NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
+TNEXT,TNOW,XX(100)
COMMON/UCOM2/A(18),B(18)
DIMENSION NSET(1)
COMMON QSET(1)
EQUIVALENCE (NSET(1),QSET(1))

```

```

I = ATRIB(2)
IF (ATRIB(1).LE.16) THEN
  VI = 930.0
  VF = VI * EXP(-0.0004965 * XX(53))
  TOF = 2014.46 * ((1.0 / VF) - (1.0 / VI))
  SIG2 = 2 * 3.1416 * ((20.0 * XX(53) / 1000.0)**2)
  BMESS = (9.8 * XX(I+59) * (TOF**2))**2
  PKSS = (5.17 / (SIG2 + 5.17)) * EXP(-0.5 * (BMESS /
+ (SIG2 + 5.17)))
  RDS = 100.0
  PKTHT = 1.0 - (1.0 - PKSS)**RDS
ELSE
  NRCS = NFIND(1,1,1,0,XX(51),2.51)
  NCS = LOCAT(NRCS,1)
  IF (ATRIB(1).LE.36) THEN
    RCS = QSET(NCS+2)
  ELSE
    RCS = QSET(NCS+4)
  ENDIF
  SRDB = 10.0 * LOG10(XX(53))
  RJSDB = ATRIB(13) + 11.0 + (2.0 * SRDB) - ATRIB(5) -
+ ATRIB(6) - RCS
  RJS = 10.0**(RJSDB / 10.0)

```

```

IF (ATLIB(1).LE.36) THEN
  CEP = SQRT((0.000000325 * RJS * (XX(53)**2)) +
+ (1890.0 * RJS) + 25.0)
ELSE IF (ATLIB(1).LE.41) THEN
  CEP = SQRT((0.00000071 * RJS * (XX(53)**2)) +
+ (2200.0 * RJS) + 58.0)
ELSE
  CEP = SQRT((0.00000562 * RJS * (XX(53)**2)) +
+ (2500.0 * RJS) + 232.0)
ENDIF
SMESS = (ATLIB(10) / CEP)**2
PKTHT = 1.0 - (0.5**SMESS)
ENDIF
IF ((PKTHT.LT.XX(I+74)).AND.(ATLIB(17).EQ.0)) THEN
  CALL SCHDL(15,1.0,ATLIB)
ELSE IF ((ATLIB(1).GT.16).AND.(ATLIB(17).EQ.0)) THEN
  ATLIB(17) = 1
  ATLIB(16) = 1.0
  CALL SCHDL(16,ATLIB(16),ATLIB)
ELSE
  IF (ATLIB(1).LE.16) THEN
    XX(I+70) = XX(I+70) - 1
  ELSE
    XX(I+72) = XX(I+72) - 1
  ENDIF
  CALL SCHDL(17,ATLIB(12),ATLIB)
  CALL MASK(PBSEE)
  SACQ = DRAND(1)
  IF (SACQ.GT.PBSEE) THEN
    PKTHT = 0.0
  ENDIF
  PT = DRAND(1)
  IF (PT.LE.PKTHT) THEN
    NTHRT = MMFE(NCLNR)
    B2 = QSET(NTHRT+2)
    NEXT = NSUCR(NTHRT)
    IF (B2.EQ.ATLIB(2)) THEN
      B18 = QSET(NTHRT+18)
      IF (B18.EQ.0) THEN
        CALL ULINK(-NTHRT,NCLNR)
      ELSE IF (B18.EQ.1) THEN
        QSET(NTHRT+3) = 0
      ELSE
        B19 = QSET(NTHRT+19)
        IF ((B19.GE.15).AND.(B19.LT.17)) THEN
          B1 = QSET(NTHRT+1)
          IF (B1.LE.16) THEN
            XX(I+70) = XX(I+70) - 1
          ELSE
            XX(I+72) = XX(I+72) - 1
          ENDIF
        ENDIF
      ENDIF
    ENDIF
  ENDIF

```

95

```

ENDIF
B12 = QSET(NTHRT+12)
CALL ULINK(-NTHRT,NCLNR)
B(1) = B1
B(2) = B2
IF ((ATTRIB(17).EQ.0).OR.(ATTRIB(17).EQ.1)) THEN
    CALL SCHDL(17,B12,B)
ELSE
    CALL SCHDL(17,1.0,B)
ENDIF
ENDIF
ENDIF
NTHRT = NEXT
IF (NTHRT.GT.0) THEN
    GO TO 95
ENDIF
XX(I+61) = 1
ENDIF
ENDIF
RETURN
END

```

SUBROUTINE OUTPUT

```

COMMON/SCOM1/ATTRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
+NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
+TNEXT,TNOW,XX(100)

```

```

PRINT*
PRINT*
PRINT*, ' DEAD TANKS = ', XX(42)
PRINT*, ' RTB A/C = ', XX(43)
PRINT*, ' KILL A/C = ', XX(44)
IPLCY = INT(XX(83))
WRITE (8,'(1X,I2,1X,F4.1,1X,F4.1)') IPLCY,XX(42),XX(44)
RETURN
END

```

Appendix G

Distribution Goodness - of - Fit Test

SAM A / SAM B X-coordinate uniform distribution input

data:

21080	26440
26550	24750
21830	21140
20790	24700
26050	21230
22890	23820
18760	25020
23310	17780
18220	20210
17010	26450
26420	
23100	
20420	
25280	
19150	

Control Data:

RUN NAME	GOODNESS OF FIT
VARIABLE LIST	OBSERVATIONS
INPUT FORMAT	FREEFIELD
N OF CASES	25
INPUT MEDIUM	CARDS
NPAR TEST	K-S(UNIFORM 17000,27000)=OBSERVATIONS
STATISTICS	ALL
READ INPUT DATA	

Output:

VARIABLE	N	MEAN	STD DEV	MINIMUM	MAXIMUM
OBSERVAT	25	22496.000	3005.262	17010.000	26550.000
1GOODNESS OF FIT				01/22/83 23.24.21.	PAGE

FILE - NONAME (CREATED - 01/22/83)

- - - - - KOLMOCOROV - SMIRNOV GOODNESS OF FIT TEST

OBSERVAT

TEST DIST. - UNIFORM (RANGE = 17000.0000 TO 27000.0000)

CASES	MAX(ABS DIFF)	MAX(+ DIFF)	MAX(- DIFF)
25	.1300	.0450	-.1300

K-S Z	2-TAILED P
.650	.792

Hypothesis :

H_0 : Distribution is Uniform (17000, 27000)

H_a : Distribution is not as stated

Test statistic:

Max (Abs Diff) = .1300

From the K-S tables for a sample size of 25, the tabulated value is .2640 for $\alpha = .05$. Since the tabulated value is greater than the test statistic, fail to reject the null hypothesis.

Appendix H

Verification of Model Operation

Verification Global Variables

XX(1) = 1800.0	XX(68) = 0
XX(2) = 1350.0	XX(69) = 0
XX(3) = 4200.0	XX(70) = 0
XX(4) = 6.0	XX(71) = 0
XX(5) = 1.0	XX(72) = 0
XX(6) = 609.6	XX(73) = 0
XX(7) = 385.0	XX(74) = 0
XX(8) = 30.48	XX(77) = 0.1
XX(9) = 1.0	XX(78) = 0.5
XX(10) = 0.0	XX(79) = 16
XX(11) = 0.0	XX(80) = 20
XX(12) = 0.0	XX(81) = 5
XX(13) = 16000.0	XX(82) = 3
XX(14) = 8000.0	
XX(15) = 16000.0	
XX(20) = 28000.0	
XX(21) = 4000.0	
XX(22) = 21000.0	
XX(23) = 11000.0	
XX(30) = 1.0	
XX(31) = 0.05	
XX(32) = (XX(22)-XX(23)) / 2.0	
XX(33) = (XX(20)+XX(21)) / 2.0	
XX(34) = 17000.0	
XX(35) = 27000.0	
XX(36) = 5000.0	
XX(37) = 15000.0	
XX(38) = 21000.0	
XX(42) = 0.0	
XX(43) = 0.0	
XX(44) = 0.0	
XX(46) = 5.0	
XX(47) = 3706.4	
XX(48) = 30.0	
XX(50) = 0.0	
XX(51) = 0.0	
XX(52) = 0.0	
XX(53) = 0.0	
XX(54) = 90.0	
XX(55) = 1	
XX(58) = 0	
XX(59) = 0	
XX(62) = 0	
XX(63) = 0	
XX(64) = 5	
XX(65) = 8	
XX(66) = 0	
XX(67) = 0	

This appendix contains the logic and computer output used to verify the proper operation of the model. Numerous runs were verified. Included in this appendix is an attack by aircraft number two, which results in a successful Maverick kill of the target. The flight path of the aircraft relative to the threat and target locations is diagramed on the final page of this appendix. The factor levels being evaluated in this attack are:

1. Threat level one (all threats included).
2. Penetration distance level two (six kilometers).
3. Airspeed level one (385 knots).
4. Weapons load level two (Mavericks and 30mm).
5. EW level one (EW radars available).

Event 13: RPSN

EV13 TNOW = 561.664067607 ATTRIB(2) = 2

Aircraft number two has returned to the CP to be briefed for another attack. The time is TNOW = 561.6 sec.

Event 14: THRT

EV14 TNOW = 564. ATTRIB(2) = 1

AAA = 0. SAM = 0.

EV14 TNOW = 564. ATTRIB(2) = 2

AAA = 0. SAM = 0.

Aircraft number two is being briefed by the FAC and aircraft number one is inbound to the CP. No air defense threats are committed against either aircraft.

Event 1: CP

EV1 TNOW = 678.6044073193 ATTRIB(2) = 2

TGT COORD = 20001.95915324 16826.08513473

Since $TNOW = 678.6$ sec, this indicates a FAC briefing time of 117 sec, since:

$$678.6 \text{ sec} - 561.6 \text{ sec} = 117 \text{ sec}$$

This time is within the uniform distribution limits of 30 sec to 120 sec. $ATTRIB(2) = 2$ defines the aircraft as aircraft number two. The target is located at $TGT\ COORD = (2, 1.68)$, X and Y coordinates measured in kilometers.

Event 2: IP

$EV2\ TNOW = 718.9784332933$ $ATTRIB(2) = 2$
 $A/C\ POS = 8000.16000$
 $BEARING = 86.06258853853$
 $ANGLE\ F = 9.474670399963$
 $A/C\ HDG = 96.00220447656$
 $PUP = 6508.669095735$
 $DISTANCE\ TO\ PUP = 6543.563061988$

$TNOW = 719$ sec is the arrival time at the IP. It took 40.4 sec to fly the 8000 meters to the IP. At 385 knots or 198.1 m/sec it would take:

$$8000 \text{ m} / 198.1 \text{ m/sec} = 40.38 \text{ sec}$$

The $A/C\ POS = (8,16)$ confirms the presence of the aircraft at the IP. The target bears 86.06 degrees from the IP. The desired run-in heading to the PUP is $BEARING + ANGLE\ F$:

$$86.06 \text{ degrees} + 9.47 \text{ degrees} = 95.53 \text{ degrees}$$

This desired run-in heading is now the mean for the heading distribution. $A/C\ HEADING = 96.0$ degrees is the actual aircraft run-in heading to the PUP. $PUP = 6508.7$ m is the computed distance from the IP to the PUP. $DISTANCE\ TO\ PUP = 6543.6$ m is the distance obtained from the normal distribution.

Event 3: ING?

EV3 TNOW = 718.9784332933 ATRIB(2) = 2

The ingress G level is set at 2 G's and the threats are allowed to begin searching for the aircraft.

Event 14: THRT

EV14 TNOW = 719. ATRIB(2) = 2

AAA = 0. SAM = 0.

CALL THREAT AAA = 0. SAM = 0.

No threats are presently committed, but the THREAT subroutine has been called.

Event 14: THRT

EV14 TNOW = 722. ATRIB(2) = 2

AAA = 2. SAM = 0.

CALL THREAT AAA = 2. SAM = 0.

Two AAA units have been committed against the aircraft.

Event 15:

EV15 TNOW = 736.1844161219 ACFT = 2 THREAT = 16.

EV15 TNOW = 736.4579840049 ACFT = 2 THREAT = 4.

The first two threats committed are now tracking. The time between being committed and tracking for these AAA sites is consistent with the threat capability.

Event 4: POP2

EV4 TNOW = 752.0021814217 ATRIB(2) = 2

TNOW = 752 sec indicates that it took 33 sec to fly to the PUP:

$$6543.6 \text{ m} / 198.1 \text{ m/sec} = 33 \text{ sec}$$

Event 14: THRT

EV14 TNOW = 754. ATRIB(2) = 2
AAA = 5. SAM = 8.

The maximum number of threats have now been committed,
so the THREAT subroutine is not called.

Event 15:

EV15 TNOW = 754.1144518713 ACFT = 2 THREAT = 6.
EV15 TNOW = 754.1844161219 ACFT = 2 THREAT = 16.
EV15 TNOW = 754.2790382608 ACFT = 2 THREAT = 25.
EV15 TNOW = 754.3494019229 ACFT = 2 THREAT = 26.
EV15 TNOW = 754.4579840049 ACFT = 2 THREAT = 4.
EV15 TNOW = 754.4678258426 ACFT = 2 THREAT = 2.
EV15 TNOW = 754.6501483974 ACFT = 2 THREAT = 23.
EV15 TNOW = 754.7039467933 ACFT = 2 THREAT = 39.
MIN RANGE
EV15 TNOW = 754.764900282 ACFT = 2 THREAT = 3.

Other threats are now tracking by this time. The aircraft
is inside the minimum range of threat 39.

Event 15:

EV15 TNOW = 756.764900282 ACFT = 2 THREAT = 3.
RANDOM NUMBER PK = .5061433940452
THREAT = 3. PK = .1213578450097
SLR = 1060.684766093 ALT = 194.3551510917 G = 2.
ASPECT = 50.9903957296 RCS = 3.95

Threat 3 is a AAA site which fires at the aircraft. It
misses because the RANDOM NUMBER PK = .5 is greater than the
PK = .12. A hand calculation of the PK follows:

$$V_f = 930 e^{-.0004965(R)}$$

$$R = 1060.7 \text{ m}$$

$$V_f = 549 \text{ m/sec}$$

$$TOF = 2014.46 \frac{1}{549} - \frac{1}{930}$$

$$TOF = 1.5 \text{ sec}$$

$$\sigma = 20(1.06) = 21.2$$

$$PKSS = \frac{5.17}{2824+5.17} \exp \left\{ -.5 \left[\frac{(44.1)^2}{2824+5.17} \right] \right\}$$

$$PKSS = .0013$$

$$PK = 1.0 - (1.0 - PKSS)^{100}$$

$$PK = .12$$

This is the same as the computer value.

Event 14: THRT

EV14 TNOW = 757. ATRIB(2) = 2

AAA = 4. SAM = 8.

CALL THREAT AAA = 4. SAM = 8.

Another AAA can now begin searching for the aircraft.

Event 16:

EV16 TNOW = 757.2790382608 ACFT = 2 THREAT = 25.

EV16 TNOW = 760.3494019229 ACFT = 2 THREAT = 26.

Threat 25 and threat 26 fire SAM A missiles.

Event 5: PUL2

EV5 TNOW = 760.504707022 ATRIB(2) = 2

TURN RATE = -11.33495381624

ALTITUDE = 323.0340449199

TURN RATE = -11.33 degrees/sec indicates a left turn
since it is negative:

$$TURN \text{ RADIUS} = (198.1)^2 / (4 \times 9.8)$$

$$TURN \text{ RADIUS} = 1001 \text{ m}$$

$$TURN \text{ RATE} = (198.1 \times 360) / (2 \times 3.14 \times 1001)$$

$$TURN \text{ RATE} = 11.33 \text{ degrees/sec}$$

A turn to the left is correct for the location of the target.
ALTITUDE = 323 m is the correct altitude for a five degree
dive angle from two nautical miles away.

Event 6: TRK2

EV6 TNOW = 763.1513874131 ATRIB(2) = 2
HEADING = 66.00220447658
BEARING = 64.41852659177
SLANT RANGE = 3709.300723883

After turning 30 degrees to the left the aircraft heading
is 66.0 degrees. The target bears 64.4 degrees from the
aircraft. The target is 1.6 degrees to the left of the
aircraft's nose because of the small navigation error induced
by the heading and distance to PUP distributions. Since
the aircraft popped up late, the target should be slightly
to the left after roll-in. The slant range to the target is
3709 m. Two nautical miles is 3706 m. Obviously the error
in slant range caused by the late pop up was negated by the
greater than desired run-in heading.

Event 16:

EV16 TNOW = 763.3494019229 ACFT = 2 THREAT = 26.
IMPACT RANGE = 2100.
LETHAL RANGE = 20.35227028791
INITIAL IMPACT RANGE = 1961.611224549
RANDOM NUMBER PK = .1173589326988
THREAT = 26. PK = .02585432221422
SLR = 2120.352270288 ALT = 323.0340449199 G = 2.
ASPECT = 106.610865517 RCS = 5.83

The SAM A from threat 26 has reached the aircraft.
Since the impact range is greater than the initial/predicted
impact range, the aircraft has turned away from the threat.

This is correct since the missile had been fired before the aircraft turned to the attack heading. This turn decreased the RCS and therefore the PK. The RCS listed is correct for the given aspect angle. Since the RANDOM NUMBER PK = .12 is greater than the PK = .03, an aircraft kill was not recorded.

Event 7: RNG2

EV7 TNOW = 763.4308200267 ATRIB(2) = 2
DIVE ANGLE = 5.051925927953
TIME TO LOCK = 6.619437985657

The dive angle being slightly greater than five degrees is due to the turn to place the target directly on the nose of the aircraft. By the time this turn was completed, the target range was inside of two nautical miles by a few meters. The Maverick missile lock-on time is 6.6 sec. At 198.1 m/sec, firing range would be:

$$198.1 \times 6.6 = 1307 \text{ m}$$

$$\text{FIRING RANGE} = 3709 \text{ m} - 1307 \text{ m}$$

$$\text{FIRING RANGE} = 2402 \text{ m}$$

Since this range is outside the minimum required lock-on range of the Maverick, the Maverick will be used.

Event 14: THRT

EV14 TNOW = 764. ATRIB(2) = 2
AAA = 5. SAM = 7.
CALL THREAT AAA = 5. SAM = 7.

Another SAM can now begin searching for the aircraft.

Event 16:

EV16 TNOW = 764.6501483974 ACFT = 2 THREAT = 23.

Threat 23 fires a SAM A missile.

Event 16:

EV16 TNOW = 765.8790382608 ACFT = 2 THREAT = 25.

IMPACT RANGE = 5565.

LETHAL RANGE = -2.154375434853

INITIAL IMPACT RANGE = 5962.467667086

RANDOM NUMBER PK = .8804209244952

THREAT = 25. PK = .001247379859464

SLR = 5562.845624565 ALT = 280.1495888839 G = 1.

ASPECT = 53.37109311552 RCS = 1.

The SAM A from threat 25 has reached the aircraft. In this case the aircraft has turned into the threat, reducing the RCS. Therefore, the PK was not high enough to make the missile shot successful.

Event 15:

EV15 TNOW = 766.0720585511 ACFT = 2 THREAT = 1.

ASPECT GREATER THAN 90 DEG

Threat 1 begins to track the aircraft, but the aspect angle is greater than 90 degrees, so threat 1 is disengaged.

Event 16:

EV16 TNOW = 767.9501483974 ACFT = 2 THREAT = 23.

IMPACT RANGE = 2257.5

LETHAL RANGE = -3.028343563856

INITIAL IMPACT RANGE = 2259.759585181

RANDOM NUMBER PK = .7672593813792

THREAT = 23. PK = .2425151277301

SLR = 2254.471656436 ALT = 243.8707840116 G = 1.

ASPECT = 82.09884244611 RCS = 16.7

The SAM A from threat 23 reaches the aircraft. The impact range and the initial/predicted impact range are nearly identical. This indicates that the aircraft had not changed course since the missile was fired; however, the aircraft was not shot down during this engagement. A hand calculation of the PK follows:

$$(J/S)db = 29.6 + 11.0 + 2(33.5) - 50.0 - 43.0 - 16 - 7$$

The slant range used in this calculation was 2254.5 m.

$$(J/S)db = -2.1$$

$$(J/S) = 10^{(-2.1/10)} = .62$$

$$CEP = \sqrt{.000000325(J/S)(2254.5)^2 + 1890(J/S) + 25}$$

$$CEP = 34.6 \text{ m}$$

$$LR = 22 \text{ m}$$

$$PK = 1.0 - .5^{(22/34.6)^2}$$

$$PK = .24$$

The hand calculated PK is the same as the computer value.

Event 8: WPN2

EV8 TNOW = 770.0502580123 ATRIB(2) = 2
 PKM = .7894334498422
 GUN AMMO = 1350.
 MAV LOAD = 2.
 TANKS KILLED ON PASS = 1.

The Maverick missile was fired with a PKM random number of .79 which was less than the .85 PK of the missile. The MAV LOAD has been decreased by one to five, and a tank kill was registered.

Event 9: RCV2

EV9 TNOW = 770.0502580123 ATRIB(2) = 2
HEADING = 64.41852659178
ALTITUDE = 207.0840069195
DEGREES TO TURN = 154.4185265918

The aircraft heading at the time of missile firing was 64.4 degrees and the aircraft had descended to an altitude of 207 m. Also, there are 154.4 degrees to turn to an egress heading of 270 degrees. This is the correct number of degrees for a left turn:

$90 \text{ degrees} + 64.4 \text{ degrees} = 154.4 \text{ degrees}$

Event 15:

EV15 TNOW = 770.0833520454 ACFT = 2 THREAT = 36.
EV15 TNOW = 770.1144518713 ACFT = 2 THREAT = 6.
EV15 TNOW = 770.1844161219 ACFT = 2 THREAT = 16.
EV15 TNOW = 770.4579840049 ACFT = 2 THREAT = 4.
ASPECT GREATER THAN 90 DEG
EV15 TNOW = 770.4678258426 ACFT = 2 THREAT = 2.
EV15 TNOW = 770.7039467933 ACFT = 2 THREAT = 39.
MIN RANGE
EV15 TNOW = 770.8419303504 ACFT = 2 THREAT = 31.

These are the threats currently tracking the aircraft. Threat 4 has discontinued tracking due to an excessive aspect angle.

Additional air defense shot attempts:

While the aircraft was turning to a 270 degree heading, four more threats fired. These were threats 16, 20, 31, and 36. None of these engagements were successful.

Event 10: EGR2

EV10 TNOW = 783.6734742243 ATRIB(2) = 2
HEADING = 270.
SAFE DISTANCE = 5432.674824233

The aircraft is heading 270 degrees, 5433m from the safe zone, where no additional threats can search for it.

Event 17:

EV17 TNOW = 786.764900282 ACFT = 2 THREAT = 3.
CONFOUNDING DELAY ELAPSED

Threat 3 had previously fired at the aircraft. The confounding delay has now elapsed, permitting the threat to again search for airborne targets. The delay involved was 30 sec as expected.

Event 14: THRT

EV14 TNOW = 800. ATRIB(2) = 1
AAA = 5. SAM = 8.
EV14 TNOW = 800. ATRIB(2) = 2
AAA = 3. SAM = 3.
CALL THREAT AAA = 3. SAM = 3.

Aircraft number one has now entered the target area, and it has a full array of threats paired against it.

Event 15:

EV15 TNOW = 800.1144518713 ACFT = 2 THREAT = 6.
EV15 TNOW = 800.1798666586 ACFT = 1 THREAT = 13.
EV17 TNOW = 800.4579840049 ACFT = 2 THREAT = 4.
CONFOUNDING DELAY ELAPSED
EV15 TNOW = 800.4678258426 ACFT = 2 THREAT = 2.
EV15 TNOW = 800.4864538331 ACFT = 1 THREAT = 15.
EV15 TNOW = 800.7039467933 ACFT = 2 THREAT = 39.

Threats are now tracking both aircraft.

Event 11: TRN2

EV11 TNOW = 811.0908435321 ATRIB(2) = 2
TARGETS LEFT = 0.
BEARING = 261.8759069826
GROUND RANGE = 12121.64900068

The aircraft has no targets left in the target area, so it will return to the CP for another FAC briefing. The CP bears 261.9 degrees from the aircraft, for a ground range of 12122 m.

Event 12: OPS

EV12 TNOW = 812.541469264 ATRIB(2) = 2
DESTINATION = 0.
HEADING = 261.7786121622
GROUND RANGE = 11835.02187946
BEARING = 261.7895033082

The turn to the CP has been completed. The aircraft heading is 261.8 degrees and the CP bears 261.8 degrees. The difference between the heading and the bearing is well within the one degree tolerance of the iterated turn procedure. The ground range to the CP is 11835 m.

Threat removal:

EV14 TNOW = 815. ATRIB(2) = 2
AAA = 0. SAM = 0.
EV15 TNOW = 815.0026814312 ACFT = 1 THREAT = 42.
EV15 TNOW = 815.1798666586 ACFT = 1 THREAT = 13.
EV15 TNOW = 815.3737372569 ACFT = 1 THREAT = 3.
EV15 TNOW = 815.4864538331 ACFT = 1 THREAT = 15.

Threats are no longer searching for or tracking aircraft number two.

Event 13: RPSN

EV13 TNOW = 872.2699043595 ATRIB(2) = 2

Aircraft number two has returned to the CP. The difference in TNOW from event 12 to event 13 is 59.7 sec. The ground range to the CP from event 12 was 11835 m, therefore:

$$11835 \text{ m} / 198.1 \text{ m/sec} = 59.7 \text{ sec}$$

This agrees with the TNOW difference.

Event 14: THRT

EV14 TNOW = 899. ATRIB(2) = 2
AAA = 0. SAM = 0.
EV14 TNOW = 900. ATRIB(2) = 2
AAA = 0. SAM = 0.

Aircraft number one has been shot down, and all entities associated with aircraft number one have been removed from the systems. Also, the THREAT subroutine no longer searches for this aircraft.

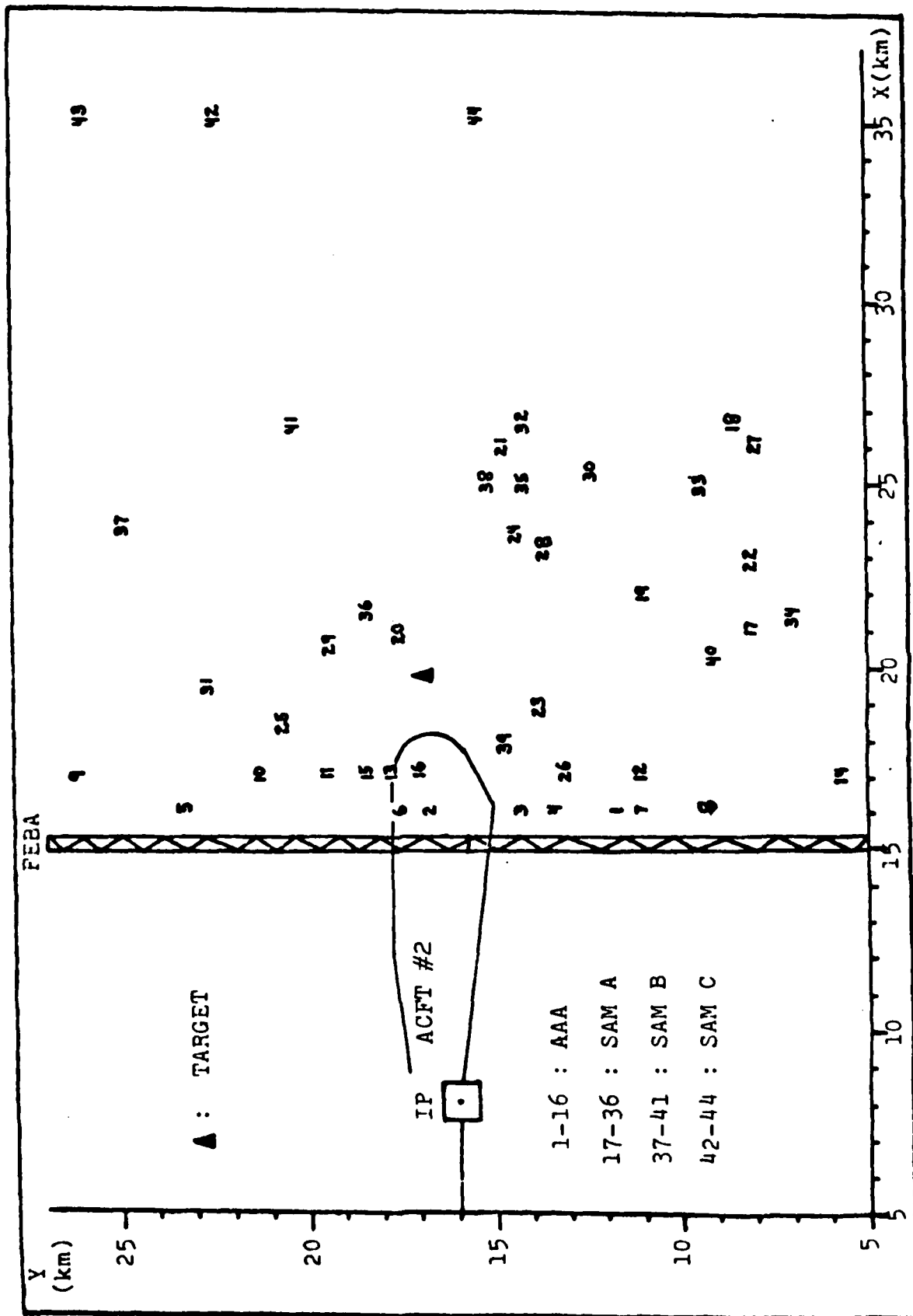
Final results:

DEAD TANKS = 12.
RTB A/C = 0.
KILL A/C = 2.

When the second aircraft is shot down or returns to base the simulation run terminates. In this run the second aircraft was shot down, terminating the run with a kill-to-loss ratio of:

$$12 / 2 = 6$$

The model was found to perform properly during this and other verification simulations. All model activities and calculations were completed accurately and in the desired sequence.



Appendix I

Five-Way ANOVA Runs

ANOVA Input Data

1 1 1 1 1 1.5
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 1 1 1 1 2 15.0
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Control Cards

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RUN NAME      KL RATIO
VARIABLE LIST THT,AS,PEN,WPN,EW,RATIO
N OF CASES    1280
INPUT MEDIUM  CARD
INPUT FORMAT   FREEFIELD
ANOVA          RATIO BY THT(1,4),PEN(1,2),WPN(1,2),EW(1,2)
STATISTICS     ALL
READ INPUT DATA
  
```

With All Interactions

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS			26026.944	7	3718.135	80.917	.001
THT			5872.890	3	1957.630	42.603	.001
AS			31.094	1	31.094	.677	.411
PEN			15964.781	1	15964.781	347.438	.001
WPN			2211.567	1	2211.567	48.130	.001
EW			1946.611	1	1946.611	42.364	.001
2-WAY INTERACTIONS			7027.138	18	390.397	8.496	.001
THT AS			848.360	3	282.787	6.154	.001
THT PEN			2515.347	3	838.449	18.247	.001
THT WPN			44.418	3	14.806	.322	.809
THT EW			103.983	3	34.661	.754	.520
AS PEN			372.492	1	372.492	8.106	.005
AS WPN			.775	1	.775	.017	.897
AS EW			1083.208	1	1083.208	23.574	.001
PEN WPN			1368.478	1	1368.478	29.782	.001
PEN EW			511.946	1	511.946	11.141	.001
WPN EW			178.130	1	178.130	3.877	.049
3-WAY INTERACTIONS			4474.404	22	203.382	4.426	.001
THT	AS	PEN	404.843	3	134.948	2.937	.032
THT	AS	WPN	31.697	3	10.566	.230	.876
THT	AS	EW	2991.043	3	997.014	21.698	.001
THT	PEN	WPN	77.026	3	25.675	.559	.642
THT	PEN	EW	78.949	3	26.316	.573	.633
THT	WPN	EW	111.477	3	37.159	.809	.489
AS	PEN	WPN	8.049	1	8.049	.175	.676
AS	PEN	EW	503.130	1	503.130	10.949	.001
AS	WPN	EW	184.908	1	184.908	4.024	.045
PEN	WPN	EW	83.283	1	83.283	1.812	.179

4-WAY INTERACTIONS			3438.748	13	264.519	5.757	.001
THT	AS	PEN	59.168	3	19.723	.429	.732
	WPN						
THT	AS	PEN	2226.958	3	742.319	16.155	.001
	EW						
THT	AS	WPN	1077.799	3	359.266	7.819	.001
	EW						
THT	PEN	WPN	57.362	3	19.121	.416	.741
	EW						
AS	PEN	WPN	17.461	1	17.461	.380	.538
	EW						
5-WAY INTERACTIONS			745.283	3	248.428	5.406	.001
IKL RATIO				12/20/82	09.53.57.	PAGE	23
THT	AS	PEN	745.283	3	248.428	5.406	.001
	WPN	EW					
EXPLAINED			41712.517	63	662.103	14.409	.001
RESIDUAL			55875.288	1216	45.950		
TOTAL			97587.804	1279	76.300		

Interactions Suppressed

SOURCE OF VARIATION		SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS		26026.944	7	3718.135	72.250	.001
THT		5872.890	3	1957.630	38.040	.001
AS		31.094	1	31.094	.604	.437
PEN		15964.781	1	15964.781	310.223	.001
WPN		2211.567	1	2211.567	42.975	.001
EW		1946.611	1	1946.611	37.826	.001
2-WAY INTERACTIONS		7027.138	18	390.397	7.586	.001
THT	AS	848.360	3	282.787	5.495	.001
THT	PEN	2515.347	3	838.449	16.292	.001
THT	WPN	44.418	3	14.806	.288	.834
THT	EW	103.983	3	34.661	.674	.568
AS	PEN	372.492	1	372.492	7.238	.007
AS	WPN	.775	1	.775	.015	.902
AS	EW	1083.208	1	1083.208	21.049	.001
PEN	WPN	1368.478	1	1368.478	26.592	.001
PEN	EW	511.946	1	511.946	9.948	.002
WPN	EW	178.130	1	178.130	3.461	.063
EXPLAINED		33054.081	25	1322.163	25.692	.001
RESIDUAL		64533.723	1254	51.462		
TOTAL		97587.804	1279	76.300		

Appendix J

Four-Way ANOVA Runs

All Interactions

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	25995.850	6	4332.642	81.357	.001
THT	5872.890	3	1957.630	36.760	.001
PEN	15964.781	1	15964.781	299.783	.001
WPN	2211.567	1	2211.567	41.528	.001
EW	1946.611	1	1946.611	36.553	.001
2-WAY INTERACTIONS	4722.302	12	393.525	7.390	.001
THT PEN	2515.347	3	838.449	15.744	.001
THT WPN	44.418	3	14.806	.278	.841
THT EW	103.983	3	34.661	.651	.583
PEN WPN	1368.478	1	1368.478	25.697	.001
PEN EW	511.946	1	511.946	9.613	.002
WPN EW	178.130	1	178.130	3.345	.068
3-WAY INTERACTIONS	350.735	10	35.073	.659	.763
THT PEN WPN	77.026	3	25.675	.482	.695
THT PEN EW	78.949	3	26.316	.494	.686
THT WPN EW	111.477	3	37.159	.698	.554
PEN WPN EW	83.283	1	83.283	1.564	.211
4-WAY INTERACTIONS	57.362	3	19.121	.359	.783
THT PEN WPN EW	57.362	3	19.121	.359	.783
EXPLAINED	31126.248	31	1004.073	18.854	.001
RESIDUAL	66461.556	1248	53.254		
TOTAL	97587.804	1279	76.300		

Interactions Suppressed

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	25995.850	6	4332.642	81.703	.001
THT	5872.890	3	1957.630	36.916	.001
PEN	15964.781	1	15964.781	301.057	.001
WPN	2211.567	1	2211.567	41.705	.001
EW	1946.611	1	1946.611	36.708	.001
2-WAY INTERACTIONS	4722.302	12	393.525	7.421	.001
THT PEN	2515.347	3	838.449	15.811	.001
THT WPN	44.418	3	14.806	.279	.840
THT EW	103.983	3	34.661	.654	.581
PEN WPN	1368.478	1	1368.478	25.806	.001
PEN EW	511.946	1	511.946	9.654	.002
WPN EW	178.130	1	178.130	3.359	.067
EXPLAINED	30718.152	18	1706.564	32.182	.001
RESIDUAL	66869.653	1261	53.029		
TOTAL	97587.804	1279	76.300		

Appendix K

One-Way ANOVA for Each Factor

VARIABLE RATIO
BY THT

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	3	5872.890	1957.630	27.236	.000
WITHIN GROUPS	1276	91714.915	71.877		
TOTAL	1279	97587.804			

VARIABLE RATIO
BY AS

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	31.094	31.094	.407	.523
WITHIN GROUPS	1278	97556.711	76.335		
TOTAL	1279	97587.804			

VARIABLE RATIO
BY PEN

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	15964.781	15964.781	249.966	.000
WITHIN GROUPS	1278	81623.023	63.868		
TOTAL	1279	97587.804			

VARIABLE RATIO
BY WPN

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	2211.567	2211.567	29.634	.000
WITHIN GROUPS	1278	95376.237	74.629		
TOTAL	1279	97587.804			

VARIABLE RATIO
BY EW

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	1	1946.611	1946.611	26.011	.000
WITHIN GROUPS	1278	95641.193	74.837		
TOTAL	1279	97587.804			

Appendix L

One-Way ANOVA of Policies

VARIABLE RATIO
BY POLICY

ANALYSIS OF VARIANCE

SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	63	41712.517	662.103	14.409	.000
WITHIN GROUPS	1216	55875.287	45.950		
TOTAL	1279	97587.804			

SUBSET 8

GROUP	GRP 36	GRP 26	GRP 19
MEAN	17.0500	19.8000	24.2750

SUBSET 9

GROUP	GRP 28
MEAN	33.4000

Appendix M

Sensitivity Analysis

Sensitivity to Number of Simultaneous Threats

VARIABLE RATIO BY POLICY

ANALYSIS OF VARIANCE					
SOURCE	D.F.	SUM OF SQ.	MEAN SQ.	F RATIO	F PROB
BETWEEN GROUPS	2	16.358	8.179	.746	.479
WITHIN GROUPS	57	624.625	10.958		
TOTAL	59	640.983			

SUBSET 1

GROUP	GRP 3	GRP 2	GRP 1
MEAN	2.8500	3.5750	4.1250

Vitae

GARY G. KIZER

Gary G. Kizer was born [REDACTED] [REDACTED] [REDACTED] [REDACTED] [REDACTED] [REDACTED]
[REDACTED] He graduated from high school [REDACTED] [REDACTED]
[REDACTED] and attended The University of Texas at Arlington,
Arlington, Texas, for two years. In 1966 he entered the Air
Force and served four years as an aircraft electrical repairman.
He left the Air Force in 1970 and returned to The University
of Texas at Arlington from which he received the degree of
Bachelor of Science in Mathematics in December 1972. Upon
graduation he re-entered the Air Force in January 1973, and
received his commission from Officer Training School in March
1973. He completed navigator training and received his wings
in December 1973. He served as an F-4 weapon systems officer
with the 43rd Tactical Fighter Squadron at Elmendorf AFB,
Alaska, the 36th Tactical Fighter Squadron at Osan AB, Korea,
and the 307th Tactical Fighter Squadron at Homestead AFB,
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[REDACTED]
[REDACTED]

Donald W. Neal

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[REDACTED] He graduated from [REDACTED] [REDACTED] [REDACTED]
[REDACTED] [REDACTED] and attended Eastern Illinois University. He
graduated in 1969 with a Bachelor of Science degree in Physics
and upon graduation entered the U.S. Army, serving a tour of
duty in Vietnam as a radar repairman. In 1973 he entered the
U.S. Air Force Officer Training School and was commissioned in
August 1973. He completed navigator training in May 1974 and
F-4 weapon systems officer training later that year. His
operational flying experience includes F-4 tours of duty in
Thailand, the Philippines, and West Germany. Prior to entering
AFIT he was an F-4 instructor weapon systems officer at
Homestead AFB, Florida. Following graduation from AFIT he will
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[REDACTED] [REDACTED]
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<p>Close Air Support Simulation FEBA Penetration Fighter Survivability Air Defenses</p>		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>Effective employment of close air support resources is essential if the rapid forward advance of a numerically superior enemy ground army is to be successfully stopped. The objective of this thesis was to develop a methodology that could examine and evaluate the various factors and interactions that influence the effectiveness of the close air support mission. The problem was studied in the context of the terrain of Central Europe and the anticipated</p>		

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threats for that region.

A model of the close air support environment was built using the SLAM computer simulation language. Five factors and their interactions were analyzed. Those factors were aircraft airspeed, aircraft weapons load, penetration distance behind the FEBA, the availability of enemy early warning radars, and the total number of threats in the area. The level of each factor was varied to determine its effect and interaction with the other factors.

Airspeed by itself does not significantly affect the aircraft kill-to-loss ratio. It does, however, contribute significantly through interactions with the other factors. Each of the other factors significantly affects the kill-to-loss ratio. Penetration distance behind the FEBA has the greatest effect upon kill-to-loss ratio.